Hydrologic and Hydraulic Assessment of Artificial Recharge in the Sparta Aquifer of Union County, Arkansas

by

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ABSTRACT

Groundwater pumping from the Sparta aquifer in Union County, Arkansas, has long exceeded natural recharge, threatening the regional water supply. An alternative water–supply project, completed in 2004, now provides treated surfacewater to local industries. This conjunctive use of surface- and groundwater has allowed the Sparta aquifer to recover somewhat. Exploring further possibilities for Union County, the author has evaluated the potential of artificial recharge by well injection. A MODFLOW groundwater model was modified to simulate the aquifer's response to artificial recharge.

Results indicate that artificial recharge in this context is impractical. Injection increases hydraulic heads only locally, with the most improvement occurring where the injection is located in an existing cone of depression in El Dorado, Arkansas. Since groundwater withdrawals are already concentrated in this area, injection only reduces the net withdrawal rate. The same result could be achieved by reducing or substituting groundwater withdrawals directly, as has been observed since the completion of the alternative-supply project. The modeling results, along with analyses of surfacewater resources, suggest that continued and expanded conjunctive use is the most viable water-management strategy in Union County.

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Rob Sowby
Cambridge, Massachusetts
May 2013

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Abbreviations and Units

AGS	Arkansas Geological Survey
ANRC	Arkansas Natural Resources Commission
AR	Artificial recharge
ASR	Aquifer storage and recovery
CFR	Code of Federal Regulations
EPA	U.S. Environmental Protection Agency
FDC	Flow-duration curve
ft	Foot
ft/d	Foot per day
ft^3/d	Cubic foot per day
ft^3/s	Cubic foot per second
GIS	Geographic information system
in.	Inch
MAR	Managed aquifer recharge
MERAS	Mississippi Embayment Regional Aquifer Study (USGS)
MGD	Million gallons per day
mi	Mile
MIT	Massachusetts Institute of Technology
MODFLOW	U.S. Geological Survey finite-difference modular groundwater-flow model
UCWCB	Union County (Arkansas) Water Conservation Board
UIC	Underground Injection Control program (EPA)
USDW	Underground sources of drinking water
USGS	U.S. Geological Survey
yr	Year

Introduction

The Sparta aquifer in Arkansas and neighboring states (Figure 1) is a deep, generally sandy, confined aquifer known for its high-quality water. Located in a temperate region well suited for agriculture and industry, there have been significant demands on its resources. For several years withdrawals from the Sparta aquifer have exceeded the natural recharge rate, creating a net loss in the aquifer's water balance (Hays 2001). Also known as water mining, the situation is not sustainable and threatens future water supplies regionally (Hays et al. 1998; McKee and Hays 2002; McKee and Clark 2003).

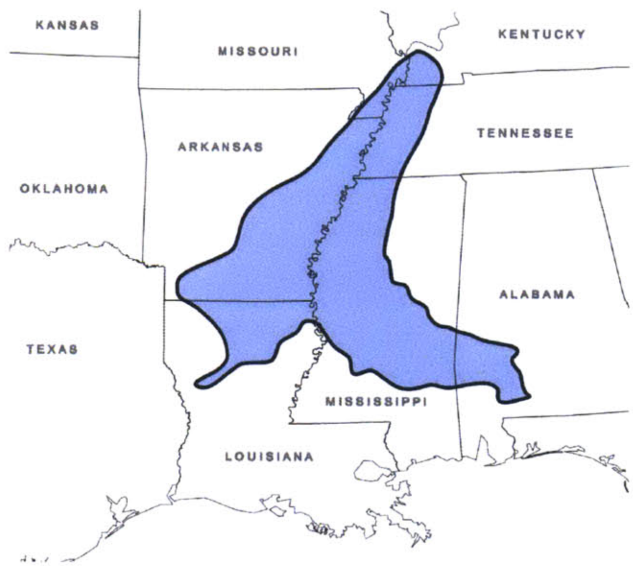

Figure 1: Location and approximate extents of Sparta aquifer.

Union County in southern Arkansas (Figure 2) has been particularly affected (UCWCB 2007; Hays 2001). Until recently, the Sparta aquifer was Union County's only viable water source. Agriculture, industry, and public supply all depended on it, and as these grew, so did demands for its high-quality groundwater. A deep and extensive cone of depression, or drawdown cone, has formed under the city of El Dorado as a result of concentrated pumping (Hays 2001; McKee and Clark 2003). For the purposes of this report, we will refer to El Dorado and the associated cone of depression as the "critical area."

Since 2004, water levels in the aquifer in and near the critical area have been rising thanks to an alternative water–supply project that will be discussed later. While the progress is encouraging, the extent of recovery remains unknown; groundwater withdrawals may continue increase to keep pace with growth and once again exceed natural recharge. Artificial recharge, which involves injection or infiltration of water from other sources to augment aquifer recharge, could be a possible method for managing groundwater resources in Union County in the future.

Figure 2: Arkansas counties, with Union County highlighted.

Geologic and Hydrogeologic Setting

The Sparta aquifer is one formation of the Mississippi embayment, which extends through portions of Missouri, Kentucky, Tennessee, Arkansas, Mississippi, Louisiana, and Alabama (Figure 4 inset). (The southern boundary of the aquifer system is difficult to delineate as freshwater gradually transitions to saltwater near the Gulf of Mexico.) As a basin, the embayment's axis trends along the Mississippi River. In a west–east cross section (Figures 3 and 4) the embayment resembles a bowl (Arthur and Taylor 1990; others). Originally, groundwater flow was generally toward the Mississippi River and toward the Gulf of Mexico, but aquifer development and concentrated withdrawals have altered that pattern somewhat.

Within the embayment the Sparta aquifer is formed by the Sparta Sand, a sequence of unconsolidated sand, silt, and clay units of Eocene age in the Claiborne group (Clark et al. 2011). In other states the Sparta Sand is known as the Memphis Sand and is included more generally in what is called the middle Claiborne aquifer (Arthur and Taylor 1990; Clark et al. 2011). In southern Arkansas the Sparta Sand, whose total thickness ranges from 100 to 1000 ft, is confined by the overlying Cook Mountain formation and the underlying Cane River formation (Clark et al. 2011; McKee and Clark 2003). See Figures 3, 4, and 6. Horizontal hydraulic conductivity ranges from 2.5 to 48 ft/d, with the lower values being typical of the deeper confined media, and the higher values being typical of unconfined areas (McKee and Clark 2003).

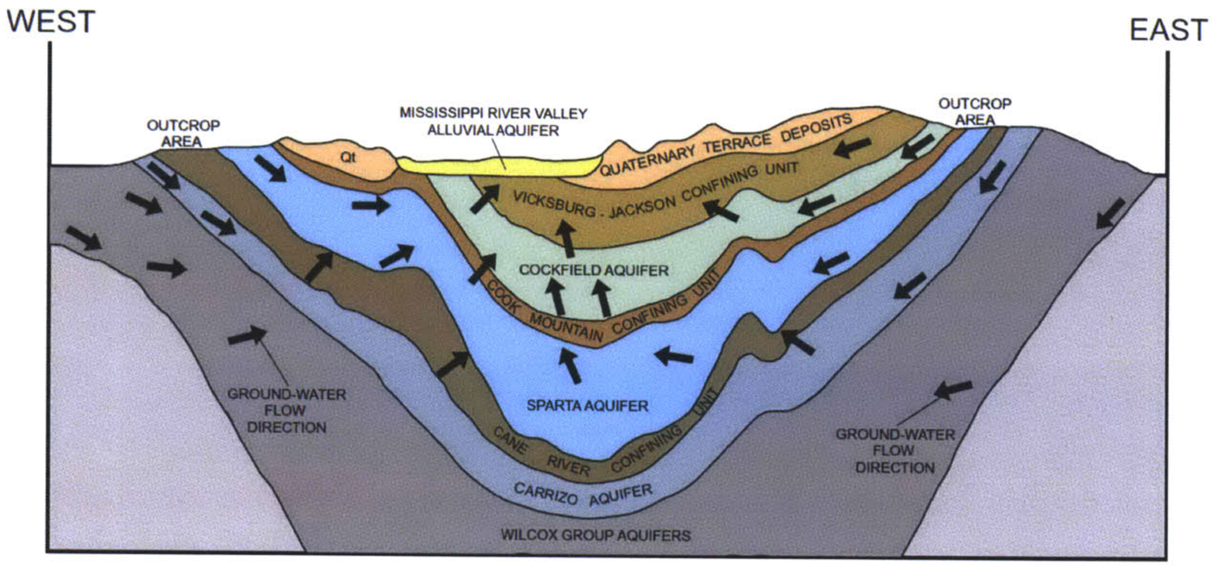

Figure 3: Hydrogeologic units in a generalized west–east cross section of the Mississippi Embayment. (McKee and Clark 2003, after Arthur and Taylor 1990)

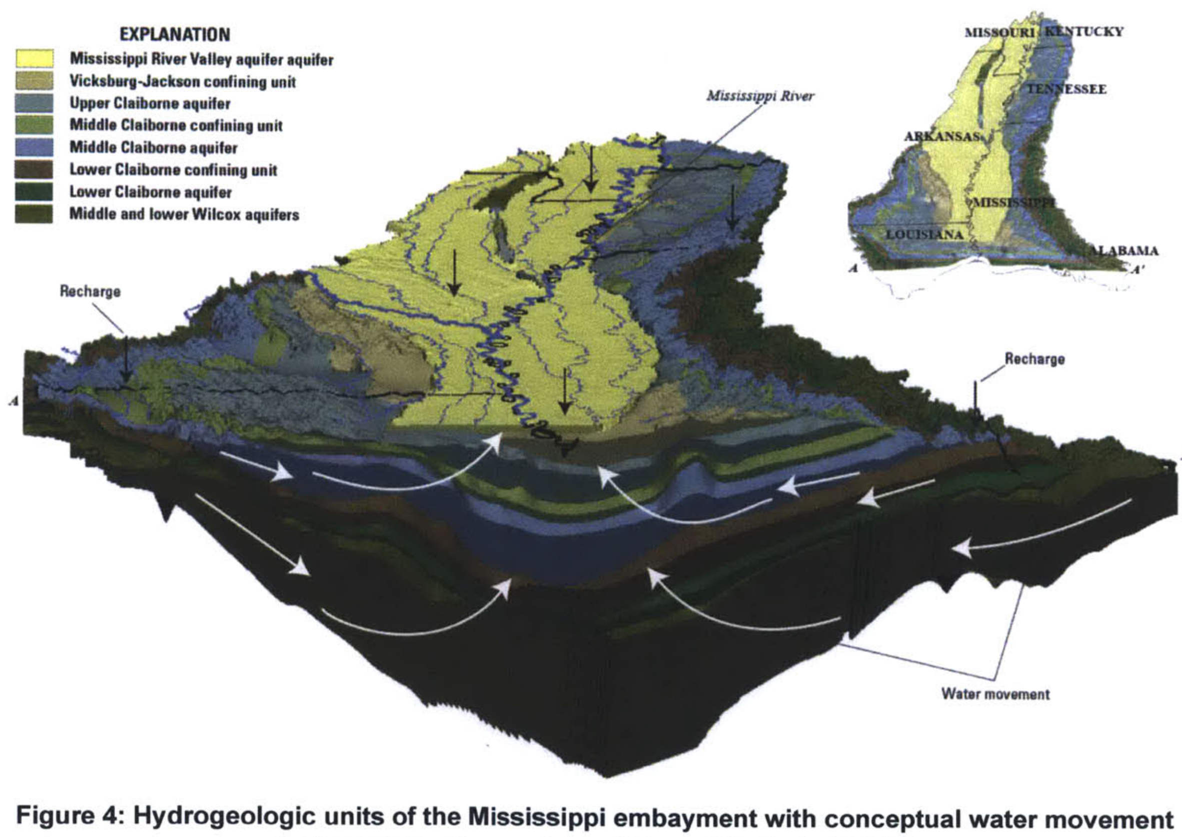

Figure 4: Hydrogeologic units of the Mississippi embayment with conceptual water movement under predevelopment conditions. (Clark et al. 2011)

As depicted in Figures 3 and 4, most of the Sparta aquifer is deep and confined, but it outcrops on both sides of the Mississippi River. Due to the geologic setting, the Sparta aquifer's western recharge zone is a narrow strip about 20 mi wide (east–west) and 350 mi long (north–south). Infiltration of precipitation is the main recharge mechanism in this area, although stream leakage, irrigation seepage, and flow from adjacent aquifers can contribute significant volumes elsewhere (Clark et al. 2011). Annual precipitation on the recharge area averages 50 in., but only a small portion enters the Sparta aquifer as recharge and this value is not well quantified (Freiwald 1984; McKee and Clark 2003; Clark and Hart 2009). Water pumped in Union County is ancient and has its provenance in this narrow outcrop area.

In Arkansas, the Sparta aquifer's western extent parallels the "Fall Line" which divides the Mississippi alluvial plain from the mountainous region to the northwest. On aerial imagery and geologic maps the Fall Line is apparent. Figure 5 shows the eastern extent of the western Sparta aquifer outcrop. Near Camden, Arkansas, the Sparta Sand and Cook Mountain formation are exposed at the surface (Figure 6). During a trip to Arkansas in January 2013, we explored the outcrop area and its geology with the help of Robert Reynolds, Sherrel Johnson, and Nancy Whitmore. Related discussion, photos, and maps are included in Appendix A.

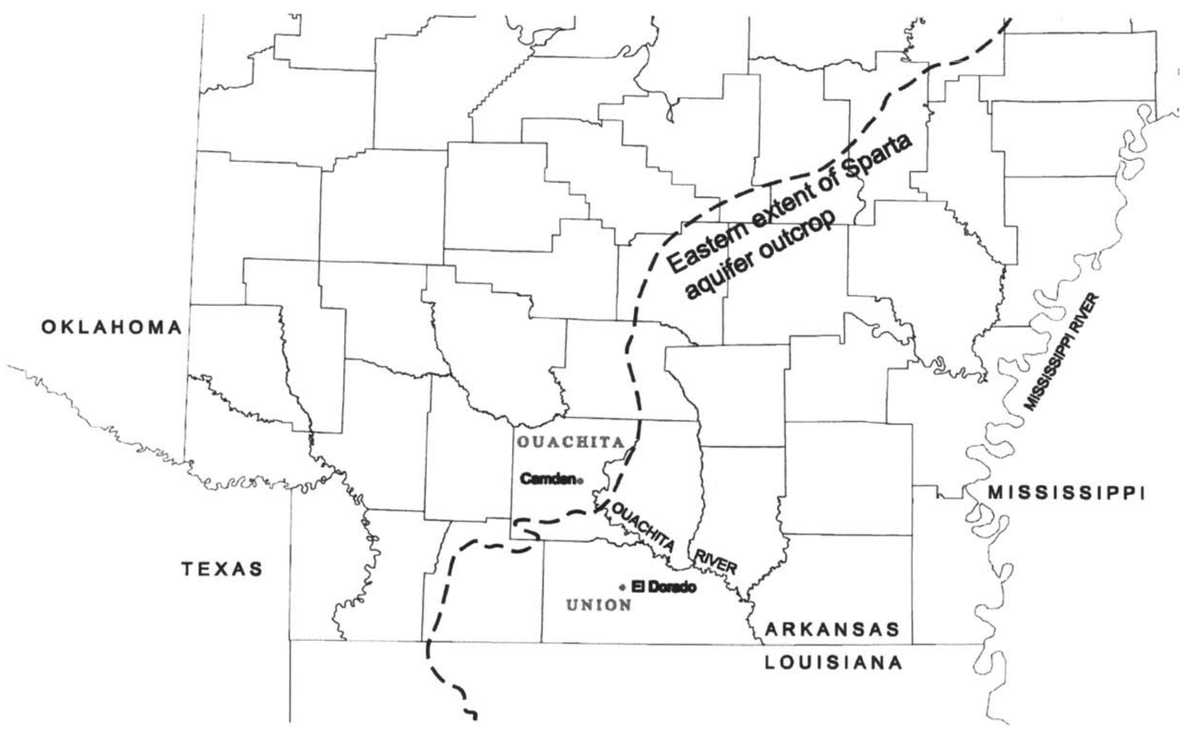

Figure 5: Sparta aquifer extent in Arkansas. (After Clark and Hart 2009)

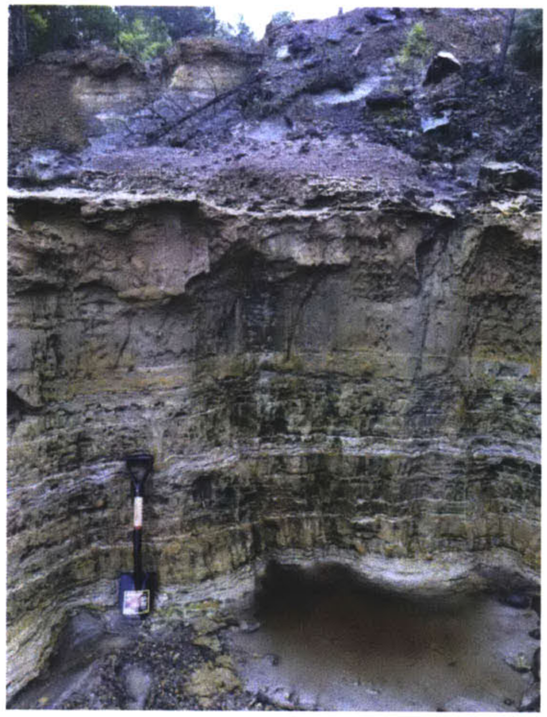

Figure 6: Top portion of Sparta Sand (foreground) with Cook Mountain confining unit above (background), near Camden, Arkansas. (Photo by Robert B. Sowby)

Union County's Success

In recent years Union County has made substantial progress toward improving the groundwater situation in their area. Refer to Appendix E for a more complete discussion of the subject. Rapidly decreasing water levels led the Arkansas Natural Resources Commission in 1996 to declare Union and four contiguous counties the state's first Critical Groundwater Area. An investigation and groundwater model by the USGS showed that a reduction to 28 percent of previous pumping rates—from 21 MGD (2,800,000 ft^3/d) to 6.0 MGD (800,000 ft^3/d)—would be required in order to avoid the irreparable damage that would occur through compaction and loss of transmissivity (Hays 2000; UCWCB 2012).

In 1997 concerned citizens responded with a coordinated, countywide effort to address the declining Sparta aquifer. One result was the formation of the Union County Water Conservation Board (UCWCB), the first entity of its kind in Arkansas, in June 1999. Authorized by Arkansas Act 1050 of 1999 with unprecedented authority over groundwater, the UCWCB continued encouraging conservation, raising funds, maintaining public support, and exploring alternatives.

Voluntary conservation between 1997 and 2003 contributed to a 15–20 percent demand reduction (UCWCB 2007; Sherrel Johnson, pers. comm., 3 May 2013). Act 1050 also authorized a conservation fee of $0.24 fee per 1000 gallons of Sparta groundwater used. In addition, Union County residents, recognizing the importance of an investment in their water resources and economic future, voted nearly 2 to 1 in February 2002 in favor of a temporary $0.01 countywide sales tax to fund a solution. With the help of engineering consultants Burns & McDonnell of Kansas City, Missouri, the board developed a water-system master plan and determined that the fastest, most cost-effective solution involved conjunctive use of surfacewater and groundwater.

Recognizing the role of surfacewater in the county's long-term supply, the board looked to the Ouachita River, the area's largest river which forms Union County's northern and eastern borders. The board then undertook the Ouachita River Alternative Water Supply Project to supply three local industries with lightly treated water from the Ouachita River. The system would replace groundwater withdrawals for some of the largest users and allow water levels in the aquifer to recover (UCWCB 2012; UCWCB 2007).

Components of the project, completed in 2004, include an intake facility (Figure 7), a clarification facility, and 23 mi of pipeline (Johnson 2006). Guided by board members Sherrel Johnson and Robert Reynolds, we toured the project in January 2013; see Appendix A for further discussion. The intake facility is located on the south bank of the Ouachita River near the town of Calion, Arkansas. The facility has a capacity of 65 MGD (8,690,000 ft^3/d) and is currently permitted for an annual average withdrawal of 50 MGD (6,680,000 ft^3/d), with a 65-MGD (8,690,000-ft^3/d) peak-day allowance (UCWCB 2007; Johnson 2006). Average 2012 intake was approximately 10.7 MGD (1,430,000 ft^3/d) (Robert Reynolds, pers. comm., 27 Feb. 2013). Sodium hypochlorite is applied at the intake for disinfection. The nearby water-clarification facility currently has a capacity of 32 MGD (4,280,000 ft^3/d), with room to expand to 64 MGD (8,560,000 ft^3/d). Water-quality monitoring occurs here. The finished water is then delivered to industrial clients throughout Union County.

Figure 7: Alternative-supply intake facility on Ouachita River. (Photo by John Czarnecki)

Since Sparta groundwater has such high natural quality, Union County residents prefer to use it for domestic rather than industrial applications, so the alternative-supply concept was ideal (Robert Reynolds, pers. comm., 12 Jan. 2013; Sherrel Johnson, pers. comm., 2 Apr. 2013). Ouachita River water is actually better for some industrial users due to its lower mineral content when compared to Sparta water, reducing the potential for mineral buildup and related problems in industrial processes (Robert Reynolds, pers. comm., 12 Jan. 2013).

The effects of the Ouachita River Alternative Water Supply Project to date have been positive. The three major industrial users in Union County have converted to the alternative supply, reducing groundwater withdrawals by 6.0 MGD (800,000 ft^3/d) in 2007 and by 10.7 MGD (1,430,000 ft^3/d) in 2012 (UCWCB 2007; Robert Reynolds, pers. comm., 27 Feb. 2013). With less reliance on the Sparta aquifer, groundwater levels in eight monitoring wells in southern Arkansas and northern Louisiana rose from 2004 to 2012—one more than 60 ft near El Dorado, Arkansas; and 11 ft in Spencer, Louisiana, some 50 mi away (Freiwald and Johnson 2007; UCWCB 2012). See Table 1. Figure 8 shows the historic water levels in the Monsanto well where, beginning in 2004, water levels have trended upward for the first time in decades. Storage and transmissivity tests conducted by the USGS and ANRC in 2012 showed that the aquifer had not sustained permanent damage. So far, conjunctive use has been an effective water-management strategy for Union County.

Table 1: Difference in Sparta Groundwater Levels at 8 USGS Real-Time Monitoring Wells

Monitoring well site	Water-level increase, Oct. 2004 to Apr. 2012 (ft)
Smackover	23.1
Spencer, LA	11.7
Magnolia	8.8
Junction City	20.4
Union School	40.1
Monsanto	63.8
Airport	35.3
Welcome Center	51.8

After UCWCB 2012

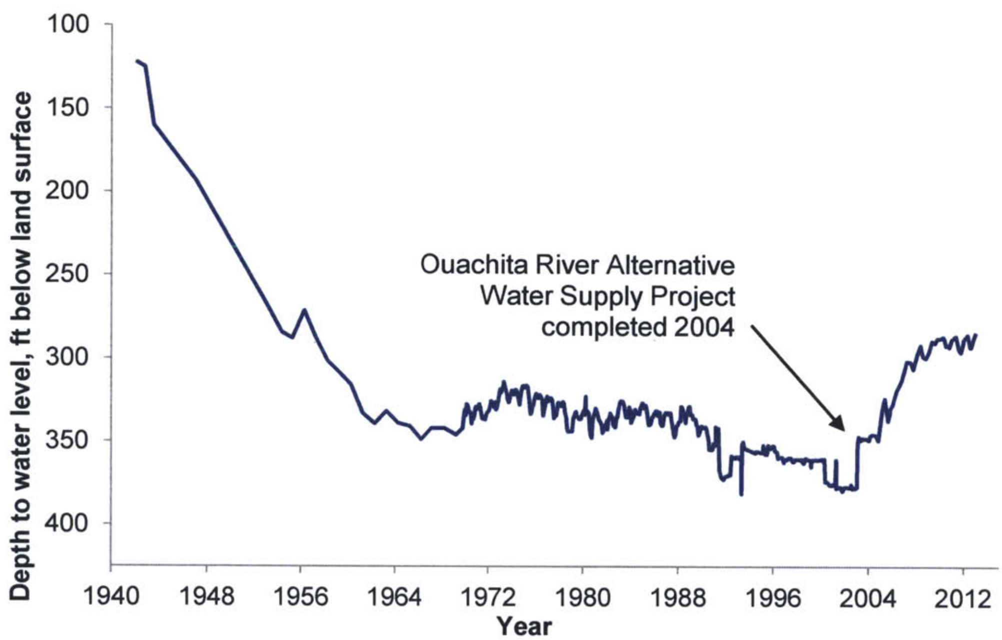

Figure 8: Historic water levels in Monsanto well. (USGS)

Artificial Recharge

Artificial recharge, also called aquifer recharge or managed aquifer recharge, is a relatively new water-management practice that has been successful many locations across the country (EPA 2012; Sheng et al. 2011; Bloetscher et al. 2005). Where natural recharge is insufficient, additional water may be artificially recharged through infiltration or injection. Generally, a spatially extensive, permeable aquifer with reasonable confinement is suitable for artificial recharging (Sheng et al. 2011; Kresic 2009; Bloetscher et al. 2005). Low-conductivity clays or high conductivity karst formations are not suitable. As a extensive, sandy, unconsolidated aquifer, the Sparta is a good candidate for artificial recharge.

The methods of artificial recharge include 1) surface infiltration and 2) well injection (Kresic 2009; Sheng et al. 2011; Bloetscher et al. 2005). Hays (2001) has modeled augmented surface recharge for the Sparta aquifer, with a hypothetical system of lakes or canals that spread water along the recharge zone. In the case of canals, additional recharge on the order of 224 MGD (30,000,000 ft^3/d) increased water levels in El Dorado some 25 ft after 7 yr. As far as we are aware, injection has not been modeled in the context of artificial recharge in the Sparta aquifer.

Artificial recharge by well injection has the following advantages that are particularly relevant to the Sparta aquifer (Sheng et al. 2011; Kresic 2009):

- Large storage volume underground (where unconfined conditions exist)
- No evaporation losses
- No eutrophication
- Minimal preemption of land surface
- Resistant to drought
- Preserved hydraulic conductivity and transmissivity

One type of artificial recharge is known as aquifer storage and recovery (ASR), in which a system of wells is used for cyclic storage and recovery of water. A conceptual ASR system is depicted in Figure 9. In the storage phase, a surfacewater body, such as a river, serves as a source. An intake system diverts water from the river and conveys it directly to a treatment facility or to storage. Treated water is then pumped into the aquifer. In the recovery phase, the same wells withdraw the water for use during dry periods. Note that artificial recharge is not the same as ASR. A critical part of the ASR definition is that the wells are dual purpose—i.e., they are used for both injection and recovery of water in a cyclic manner. While ASR may be appropriate in this context, we will focus on the storage component rather than recovery and use the broader definition of artificial recharge.

A conceptual ASR system is shown in Figure 9. As can be inferred from the described system, the costs of implementing ASR include:

- Well development
- Diversion and storage
- Pre-injection water treatment
- Pumping and operation

Although economic factors are not within the scope of this study, a comprehensive economic analysis would be necessary to determine overall feasibility.

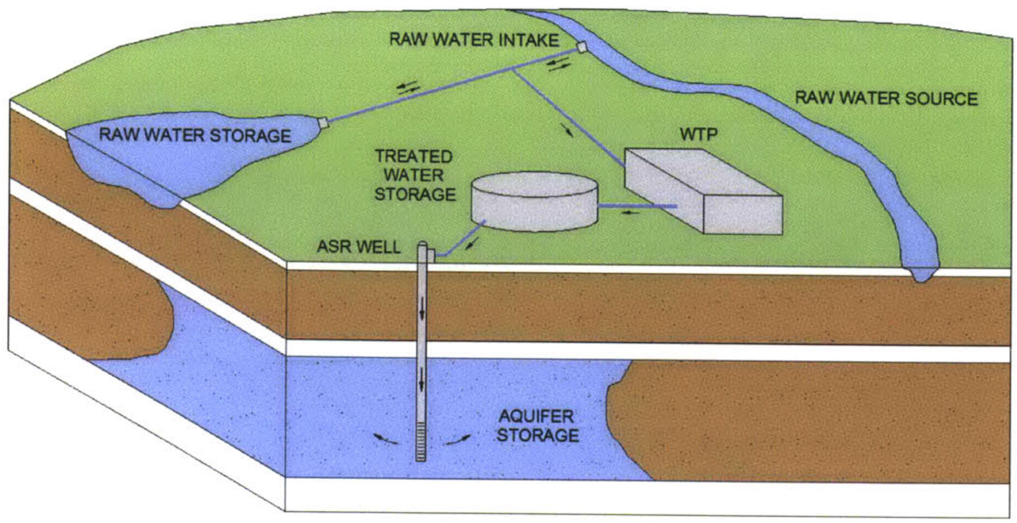

Figure 9: Artificial recharge–system concept.

Because introducing raw surfacewater into a groundwater system could have undesirable effects on water quality, federal and state regulations exist to protect underground drinking-water sources. Wells serving the purpose of artificial recharge are designated as Class V injection wells by the EPA and are regulated by the EPA's Underground Injection Control (UIC) program (EPA 2009; Bloetscher et al. 2005). Under the UIC program, the injected water (the injectate) must meet National Primary Drinking Water Regulations. States with more stringent drinking-water standards may claim primacy and choose to add more requirements beyond EPA's regulations. Arkansas was given the authority to administer the UIC program as a primacy state in 1982.

The Arkansas Department of Environmental Quality oversees activities involving Class V wells in the state. The applicable regulations are presented in the Arkansas Underground Injection Control Code and the Code of Federal Regulations (40 CFR 124, 144–146) (Arkansas Pollution Control and Ecology Commission 2005; Arkansas Department of Environmental Quality 2004). The key criteria for injection water are compliance with drinking-water standards and no harming of public health by endangering underground sources of drinking water. However, UIC only regulates the quality of the injectate with regard to potential health impacts. No additional regulations are specified for water quality in the storage zone or for the recovered water. If stored water is destined for recovery, in-situ monitoring of stored-water quality and geochemical interactions of recharged water with native groundwater is required to determine appropriate end-use of the stored water.

The success of artificial recharge depends in large part on how much stored water meeting the water-quality standards can be recovered for beneficial uses. Stored water that has been treated to meet water-quality standards and has considerable economic value. Usually, an efficiency goal is designed with reference to a local surfacewater-storage capacity. Due to high evaporation, transpiration, seepage, and conveyance losses typically associated with surfacewater bodies, any recovery efficiency that is higher than existing surfacewater storage is generally considered beneficial (Kresic 2009).

Feasibility Considerations

In order to simplify the feasibility analysis, we made the following assumptions:

- Hydrologic and hydraulic feasibility is independent of overall feasibility. Total feasibility will require further analysis of economic, political, regulatory, design, and operational issues.
- The injectate has been pre-treated to drinking-water standards to satisfy the regulatory requirements. Treatment methods besides those necessary for geochemical compatibility were not addressed.

Our approach involved investigating the following issues and guiding questions for hydrologic and hydraulic feasibility of artificial recharge in the Sparta aquifer:

a) Aquifer Improvements

What is the relationship between injection flux, head increases, and time scale for each location?

The primary concern of artificial recharge is its capacity to provide beneficial effects in the system, i.e., to improve aquifer conditions. Specifically, increases in hydraulic heads in the critical area were the primary criteria. As will be discussed later, a USGS groundwater model was the primary tool for investigating this criterion.

b) Source Water

Is there a water source available that is accessible, treatable, and abundant enough?

Generally, any water supply that meets primary drinking-water standards, with treatment as necessary, can be a potential source of recharge water. Our evaluation of potential sources addressed the following questions:

- Can the water be treated to drinking-water standards?
- Is the potential source sporadic or consistent?
- Can the source meet the demands of the system? (Is there enough water?)
- How close is the potential water source?

In short, the criteria for a source water were quality, availability, quantity, and proximity.

Of particular interest was how the Ouachita River Alternative Water Supply Project could be used as an injection source as well as for its current conjunctive-use purposes. Since the facility already withdraws water from the Ouachita River, treats it, and conveys it into Union County, this was a promising starting point. The facility can expand to, and is currently permitted to, accommodate greater withdrawals. Bloetscher et al. (2005) discuss how using excess treatment-plant capacity for ASR in this manner can improve overall water-system efficiency.

To help assess water availability, we analyzed streamflow data and developed flow-duration curves for local rivers and streams. See Appendices B and C for details of the source water–quantity evaluation and the Ouachita River water balance, respectively.

c) Geochemistry and Water Quality

What additional treatment is necessary to ensure geochemical compatibility, maintain groundwater quality, and avoid well clogging?

While the injectate may meet drinking-water standards, additional treatment may be needed to ensure geochemical compatibility and water quality in the aquifer. Depending on the potential of geochemical interactions between injected water, native groundwater, and the geologic matrix, one or more of the following supplementary treatments may be necessary:

- Removal of oxygen to reduce oxidation–reduction potential
- Removal of chorine residuals
- Disinfection

Mixing treated surfacewater with native groundwater will certainly affect water quality. Contaminants of interest include disinfection byproducts, most notably trihalomethanes) and haloacetic acids, arsenic, a naturally occurring but toxic element; iron and manganese, which can dissolve into or precipitate out of groundwater; and microorganisms introduced through the injectate.

Well clogging has been identified as the major reason for low performance of artificial-recharge systems, particularly ASR systems. Multiple factors contribute to well clogging, including (Cole 2009):

- Suspended solids in source water
- Biofilm production on well screens
- Carbonate precipitation

- Remobilization of drilling mud or fines
- Air entrainment and gas binding

Appropriate pre-treatment of injectate and geochemical monitoring are effective strategies to control the aforementioned issues. If clogging is observed during operation, periodic purging or backflushing should be scheduled. Previous ASR projects and studies have shown that the frequency of backflushing is on the order of a few times per month (Cole 2009). In our study we assumed that existing wells could be used for recovery, while injection wells could be used primarily for recharging, with the exception of regular backflushing as required to prevent mineral accumulation.

While we assumed that the potential injectate would meet drinking-water standards through standard treatment, Zhu (2013) investigated other issues related to geochemical compatibility, groundwater quality, and well performance. Zhu's results, based on hypothetical injection of treated water from the Ouachita River Alternative Supply Project, indicated that the injectate would be of very high quality in terms on ionic content. However, removal of oxygen to reduce the oxidizing potential may be required to avoid iron precipitation.

MODFLOW Methodology

Various computer models have been developed to help assess groundwater resources in the Mississippi embayment (Freiwald and Clark 2011; Freiwald 2005). The most recent model is the Mississippi Embayment Regional Aquifer Study (MERAS) by Clark and Hart (2009). The MERAS, which is meant to encompass the entire embayment system, incorporates current geological knowledge and pumping parameters. However, at the time of our project, the MERAS model was being redeveloped and was not available for our use. Instead, we employed an earlier model by McKee and Clark (2003) that simulates only the Sparta aquifer, with relevant boundary conditions. Although not as recent as the MERAS, it is the latest available model for the region and we considered it to be adequate for the comparative purposes of this study. The active model area covers 38,220 mi^2 in southern Arkansas, northern Louisiana, and a portion of Mississippi with 38,220 active cells of 1 mi^2 each. For further documentation of the model, see McKee and Clark (2003).

The model is built on MODFLOW-2000, a modular finite-difference code developed by the USGS to solve the groundwater-flow equations for three-dimensional transient flow (Freeze and Cherry 1979; McKee and Clark 2003):

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) + W = S_s \frac{\partial h}{\partial t}$$

where h is hydraulic head [L]; K_x, K_y, and K_z are hydraulic conductivities in the x, y, and z directions [L/T]; W is the source/sink term (the well term, positive for sources and negative for sinks) as volumetric flux per unit volume [1/T]; S_s is the specific storage [1/T]; and t is time [T].

Brian Clark of the USGS provided us a MODFLOW package of their Sparta model. We imported the model into the third-party interface GMS 9.0 (Groundwater Modeling System) to begin preliminary setup. The model grid had to be translated north and east and rotated clockwise by approximately 47.4° to match the predefined coordinate system and grid-boundary shapefile. It is important to note that MODFLOW is unaffected by translation or rotation of the grid; only the absolute size and boundary conditions are germane to the flow equations. We added basemaps and obtained GIS data of state and county boundaries from the USGS National Atlas. Before making any actual modifications, we ensured that the model, as received, matched the simulated 1997 potentiometric surface documented by the USGS (Figure 10; note the cone of depression in Union County). The model has 2 layers; Layer 2, being the lower water-bearing unit of the Sparta Sand, is the one of interest and is the one shown in all MODFLOW-derived results in this report.

To model the aquifer's response to artificial recharge, we chose three locations for recharge wells. See Table 2 and Figure 11. Location 1 was chosen as the deepest point in the critical area (the point of lowest simulated hydraulic head). Location 1 is in El Dorado, targeting the critical area with the purpose of improving hydraulic heads relatively rapidly. Here, conditions are usually confined and the aquifer is deep; some dewatering of the aquifer has occurred as hydraulic heads have dropped below the top of the Sparta Sand. Location 2 models injection between El Dorado and the eastern recharge area. In Location 3, the farthest from the critical area, we modeled injection with the assumption that this would allow maximum time for natural filtration through the porous media and improve water quality.

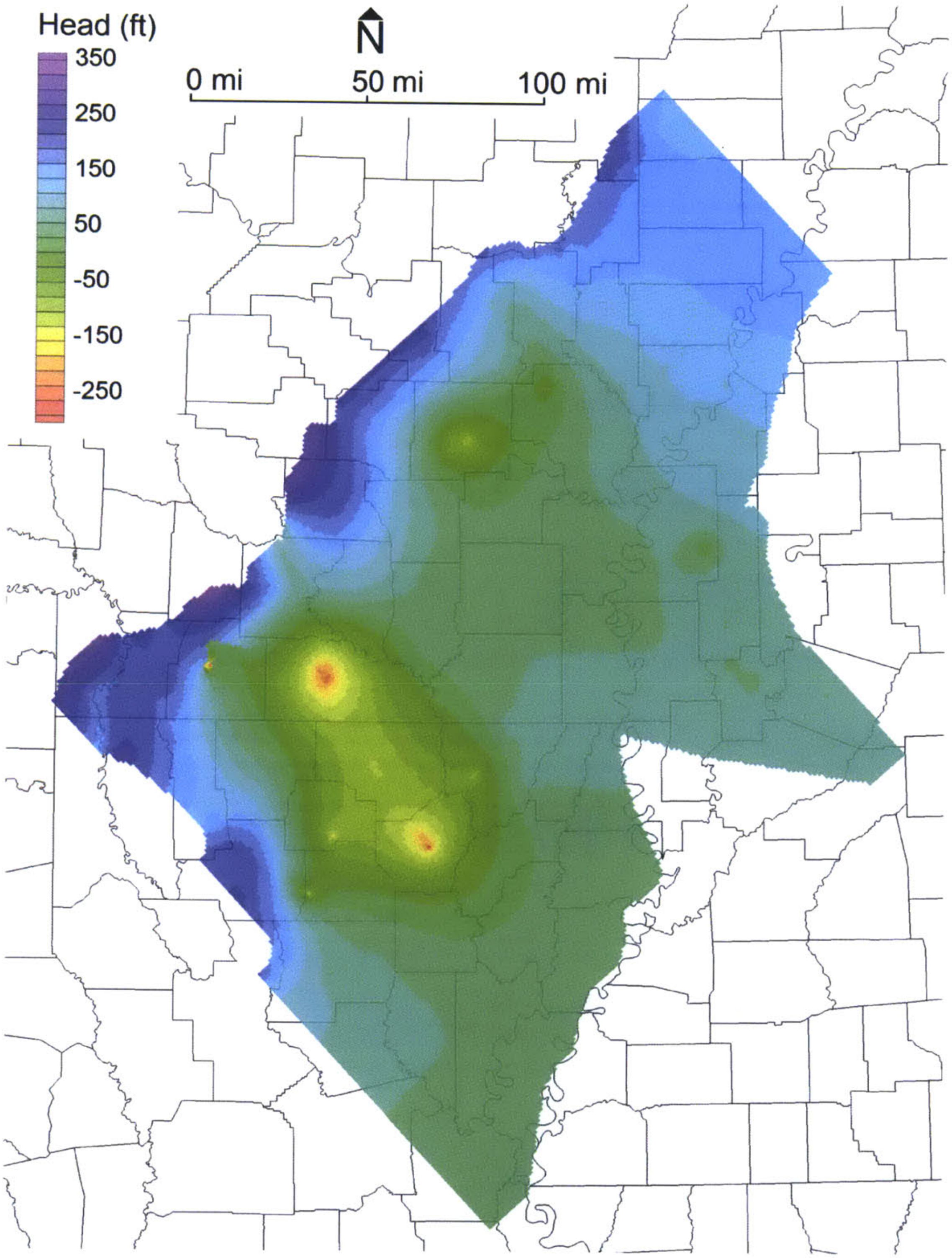

Figure 10: Simulated 1997 potentiometric surface. (Basemap data from USGS National Atlas)

Table 2: Injection Well Locations and Properties

Property	Location 1	Location 2	Location 3
Location description	Point of lowest simulated hydraulic head (deepest depression); El Dorado, Union County	Midway between Locations 1 and 3; near Smackover Creek, Ouachita County	Near edge of model; Ouachita County
Grid address (i, j, k)	193, 64, 2	193, 46, 2	193, 29, 2
Coordinates (approx.)	33°12'00" N, 92°40'15" W	33°23'30" N, 92°53'00" W	33°34'30" N, 93°04'45" W
Horizontal hydraulic conductivity*	16.1 ft/day	16.1 ft/day	47.9 ft/day
Porosity*	0.3	0.3	0.3
Layer 1 top elevation	–32 ft	–80 ft	72 ft
Layer 1 bottom elevation (Layer 2 top elevation)	–182 ft	–183 ft	44 ft
Layer 2 bottom elevation	–567 ft	–447 ft	–65 ft

* Values from Layer 2.

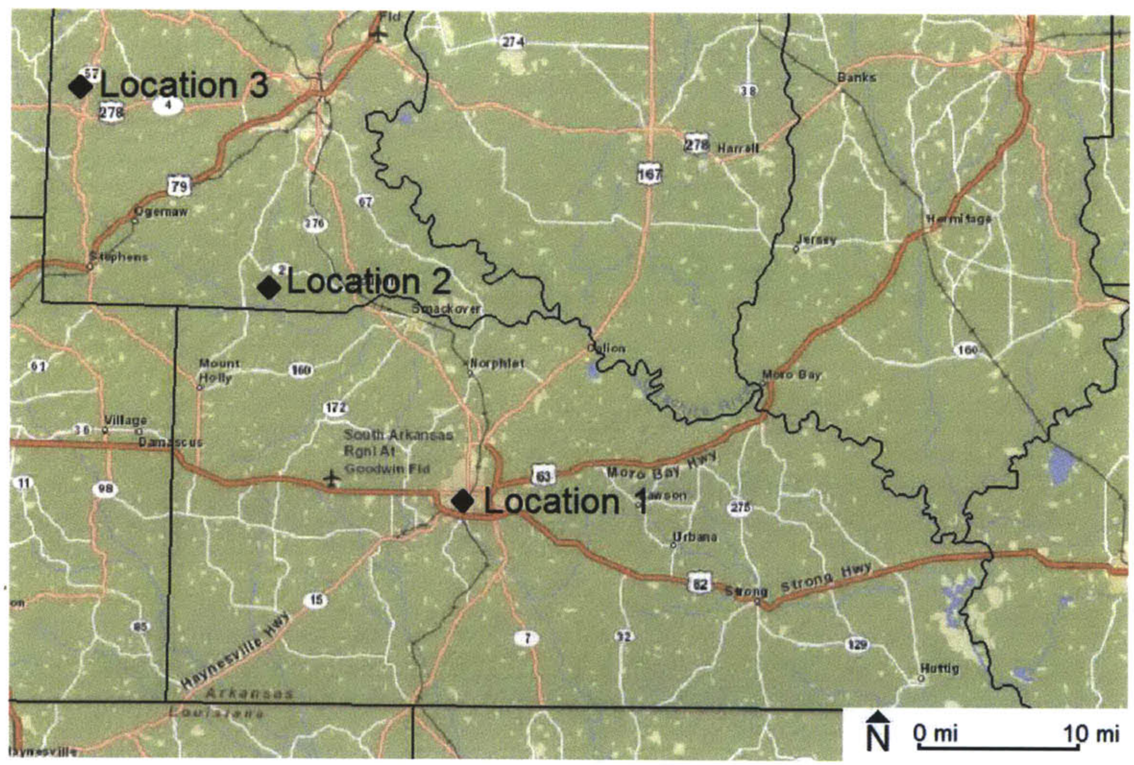

Figure 11: Three locations used for injection-well modeling. (Basemap data from USGS National Atlas and Esri)

The original model was divided into 28 stress periods from 1897 to 1997. Additional stress periods were included to extend the model through 2057 and to equilibrium conditions (steady-state simulation). We initially chose 5-yr stress periods, but preliminary modeling suggested that smaller time steps near the beginning of injection (2017–2027) were more appropriate. The additional stress periods for our modeling are outlined in Table 3.

Table 3: MODFLOW Stress-Period Additions

Stress Period	Year	Value (days since 1897)	Stress period length (d)	Stress period length (yr)	Injection duration, t_{inj} (yr)
28	1997	36525.00	1826.25	5	-
29	2002	38351.25	1826.25	5	-
30	2007	40177.50	1826.25	5	-
31	2012	42003.75	1826.25	5	-
32	2017	43830.00	365.25	1	0
33	2018	44195.25	365.25	1	1
34	2019	44560.50	730.50	2	2
35	2021	45291.00	730.50	2	4
36	2023	46021.50	730.50	2	6
37	2025	46752.00	730.50	2	8
38	2027	47482.50	1826.25	5	10
39	2032	49308.75	1826.25	5	15
40	2037	51135.00	1826.25	5	20
41	2042	52961.25	1826.25	5	25
42	2047	54787.50	1826.25	5	30
43	2052	56613.75	1826.25	5	35
44	2057	58440.00	1826.25	5	40
45	Steady state simulation				

In MODFLOW, sources and sinks (wells) are averaged over the cell and represented as a single value at the center. In this model, where the active area has been discretized into 1 mi × 1 mi cells, a single grid cell may represent multiple wells. Sinks in the groundwater system, such as pumping, are defined as negative; sources, such as injection and recharge, are positive.

While actual pumping rates in the critical area have declined since the introduction of Ouachita River Alternative Water Supply Project in 2004, we did not adjust the model's well parameters to reflect this change. For the 1997 stress period, the model's predefined pumping totaled approximately 12 MGD (1,600,000 ft^3/d) in the El Dorado area. Predicting future demands and updating current pumping fluxes, which would require calibrating the model with current water-level data, were beyond the scope of this project. Instead, we chose to maintain the model's 1997 rates for 20 yr and begin injection scenarios in 2017. Any head changes due to reductions in pumping rates after 1997 (i.e., as a result the alternative-supply project) would be in addition to the results presented here. With the 1997 pumping rates held constant and extended, simulated hydraulic heads continue to decrease in the critical area, warranting some attention to future water use.

With these values in mind, we designed a series of simulations for artificial recharge in each of the three locations. Injection rates ranged from 0 to 6.0 MGD (800,000 ft^3/d), with the upper bound chosen as 50 percent of the 1997 estimated total withdrawals in the El Dorado area as discussed above. This range is reasonable for a system of wells. Note that the fluxes chosen for our modeling are considerably less than the approximately 224 MGD (30,000,000 ft^3/d) Hays (2001) used when modeling augmented surface recharge.

At Location 1 the grid cell chosen for injection already had defined pumping rates from the original model, as did most cells in and near El Dorado, being one of the most heavily pumped areas of the Sparta aquifer. Where injection and pumping overlap, adding injection makes the flux more positive (less negative). From a modeling perspective this is equivalent to reducing withdrawals, which may also be of interest in actual application. Since wells were not previously defined in grid cells at Locations 2 and 3, we added source/sink parameters to represent the injection fluxes. For a given simulation the injection parameter was transient, being zero until 2017 and constant thereafter. For a given location, the magnitude of the source/sink parameter beginning in 2017 was the variable in each simulation.

Due to energy constraints, a single injection well may not have the necessary capacity for a given injection scenario. Injection rates are physically limited by well diameter and head losses due to friction in the well casing and bottom-hole driving pressure at the injection horizon (Bloetscher et al. 2005). The lumped injection rate used for modeling must be divided by a design rate for a single well to give the number of wells needed in an artificial-recharge system. Further, while the model considered injection rates to be constant, in application there would be phases of injection, rest, and backflushing, and the actual operational rate would be higher. While well design is not discussed in detail here, the success of any injection system depends on appropriate well design.

As the measure of relative aquifer improvement we chose the change in hydraulic head (Δh) from 2017 levels:

$$\Delta h = h(Q_{\text{inj}}, t_{\text{inj}}) - h_0$$

Where, for the model cell corresponding to each of the three locations, h_0 is the 2017 simulated hydraulic head and h is the simulated hydraulic head at a future time as a function of injection rate (Q_{inj}) and injection duration (t_{inj}). This calculation was performed for each of the three locations with varying injection rates and injection durations.

Each simulation gave hydraulic heads in each cell for each stress period. To depict this data, we graphed the change in hydraulic head versus injection duration (Δh versus t_{inj}) for each injection rate (Q_{inj}), as well as the change in hydraulic head versus injection rate (Δh versus Q_{inj}) for each injection duration (t_{inj}). Profiles and maps of the potentiometric surface were also prepared for comparison of spatial influences.

MODFLOW Results

The results of the artificial-recharge simulations are shown in Figures 12–29. The model input and output used to create the figures are tabulated in Appendix D.

Figure 12 depicts a cross section of the simulated potentiometric surface along row 193 of the model grid, which runs from the outcrop area in eastern Ouachita County southeast through Locations 1, 2, and 3 and through the critical area in Union County.

In Figures 13–15, cumulative simulated hydraulic-head changes are plotted against the injection duration for each injection rate. Note that the vertical scales on these figures have been adjusted to best show the data. Hydraulic-head data is at the El Dorado cone of depression (Location 1, cell 193, 29, 2) in each case. This is useful for understanding how hydraulic heads change over time for given injection rates.

Figures 16–18 are another form of the data in the Figures 13–15, this time with injection rate along the abscissa and each injection duration being a separate dataset.

Figures 19–21 show cross sections of the simulated potentiometric surface after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at the three locations.

Potentiometric surfaces for the three injection scenarios and the base scenario are shown in Figure 22–25. For Figures 26–29 we computed the difference in heads over the 20-yr period (2037 simulated heads minus 2017 simulated heads).

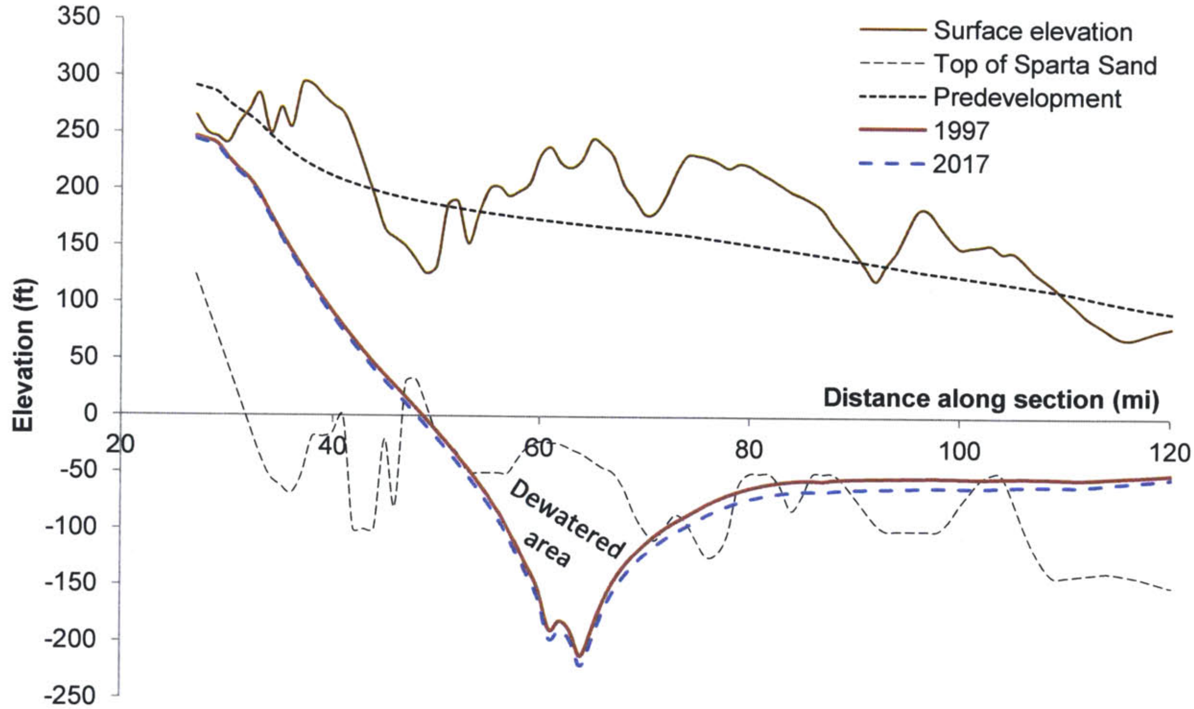

Figure 12: Comparison of potentiometric-surface profiles under simulated predevelopment conditions, 1997 conditions, and 2017 conditions (with 1997 pumping rates).

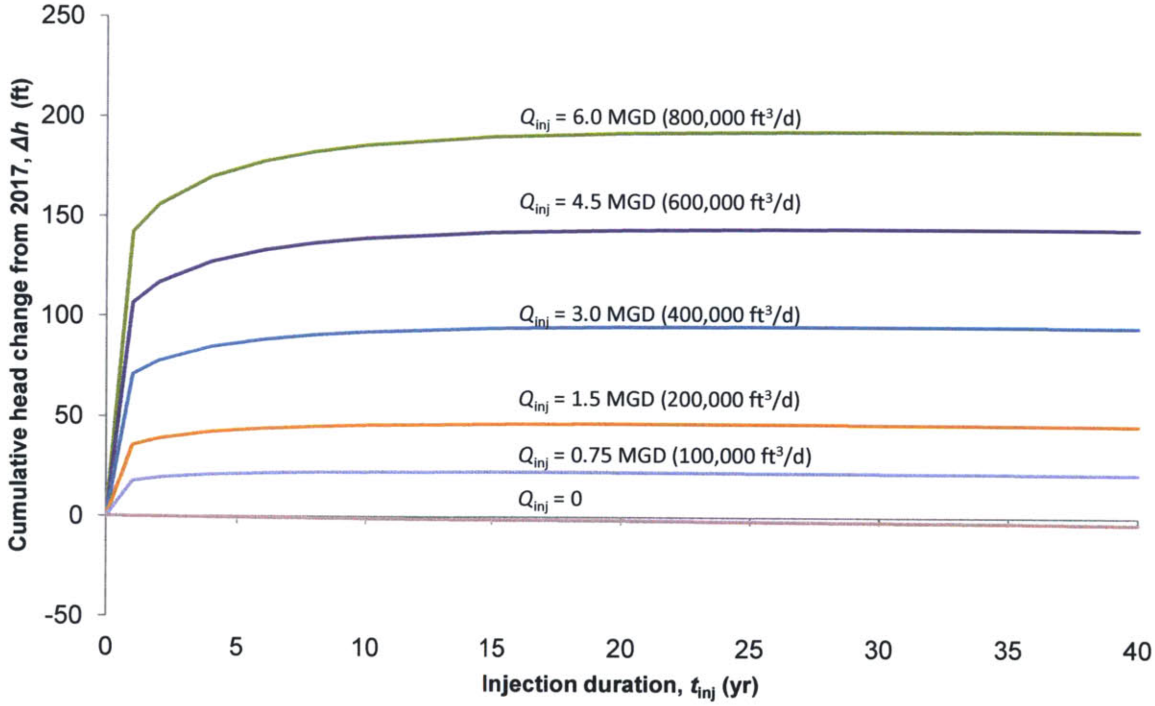

Figure 13: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection duration for injection (or reduction of withdrawals) at Location 1.

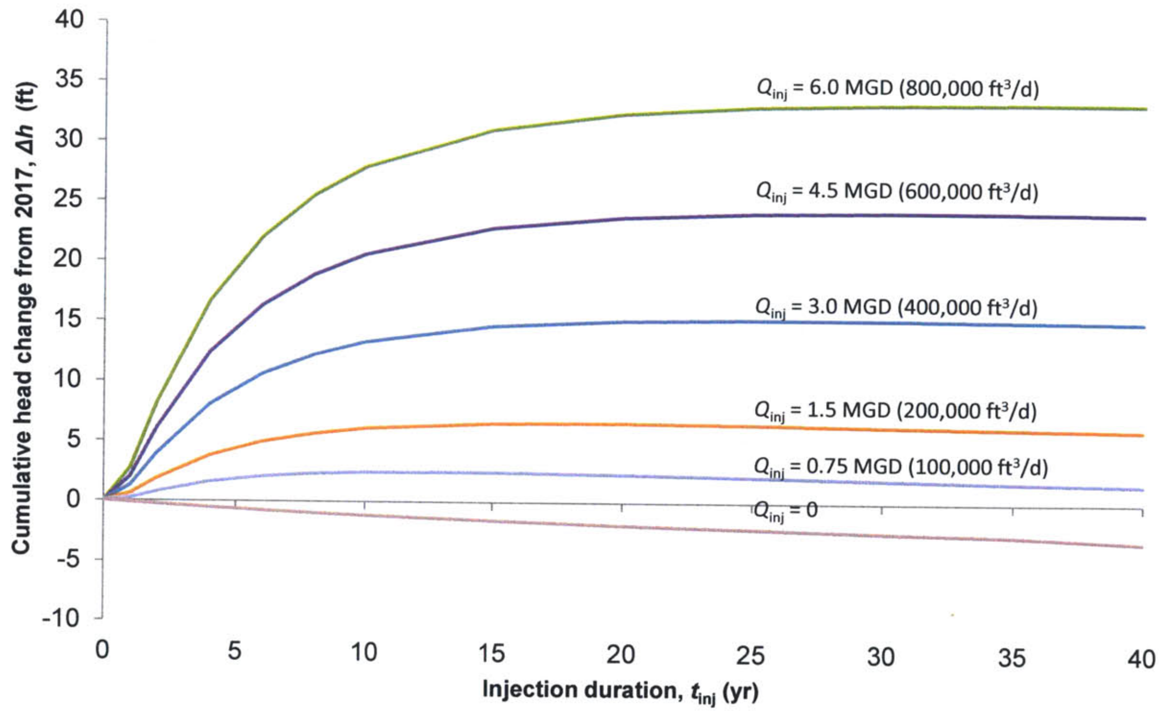

Figure 14: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection duration for injection at Location 2.

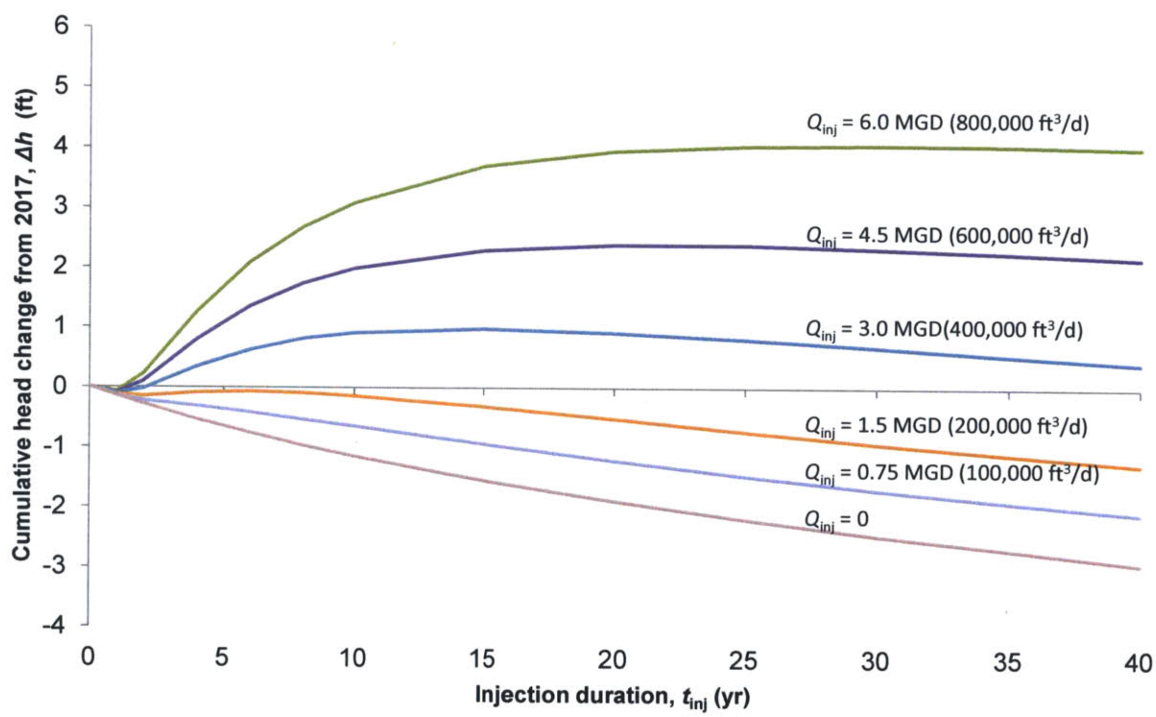

Figure 15: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection duration for injection at Location 3.

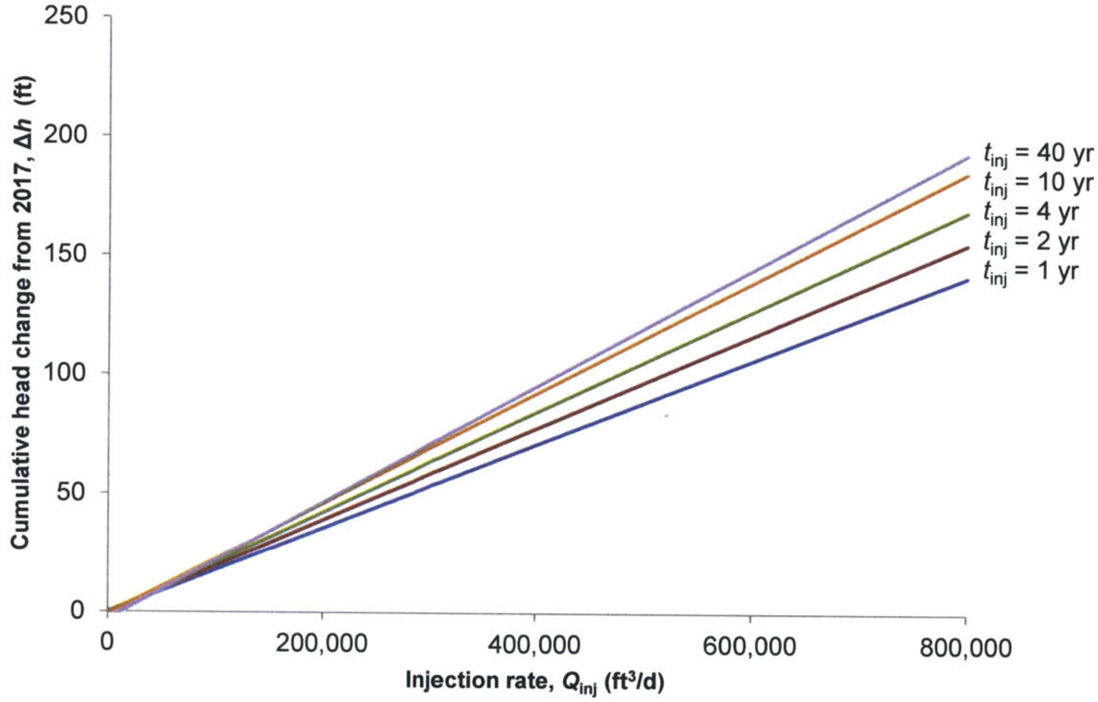

Figure 16: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection rate for injection (or reduction of withdrawals) at Location 1.

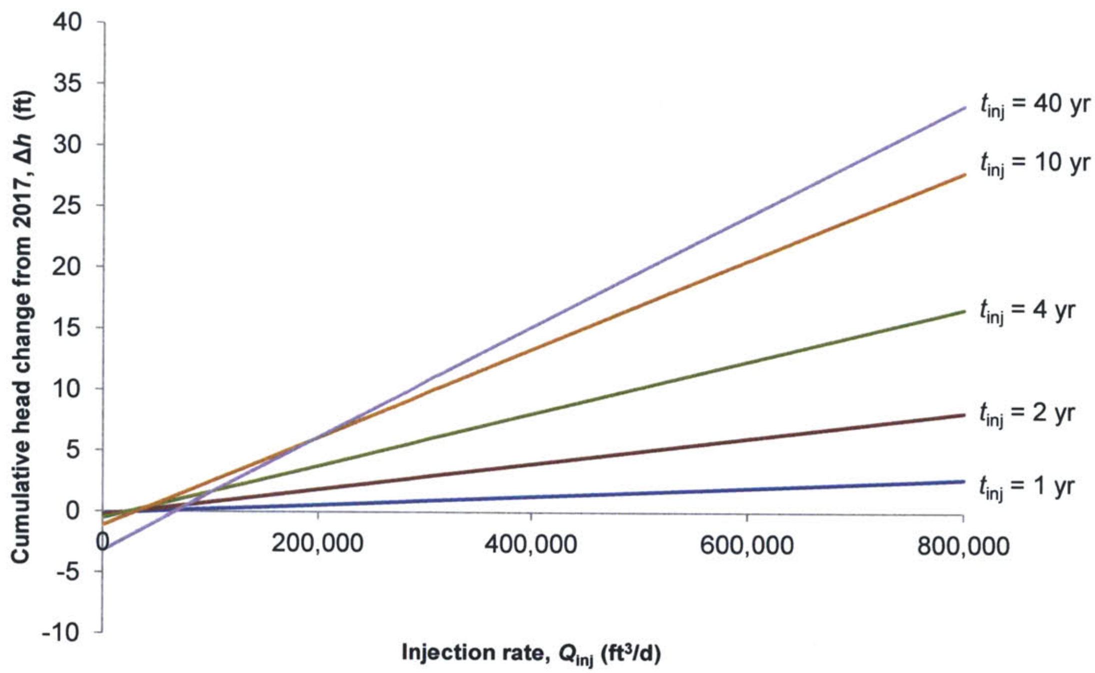

Figure 17: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection rate for injection at Location 2.

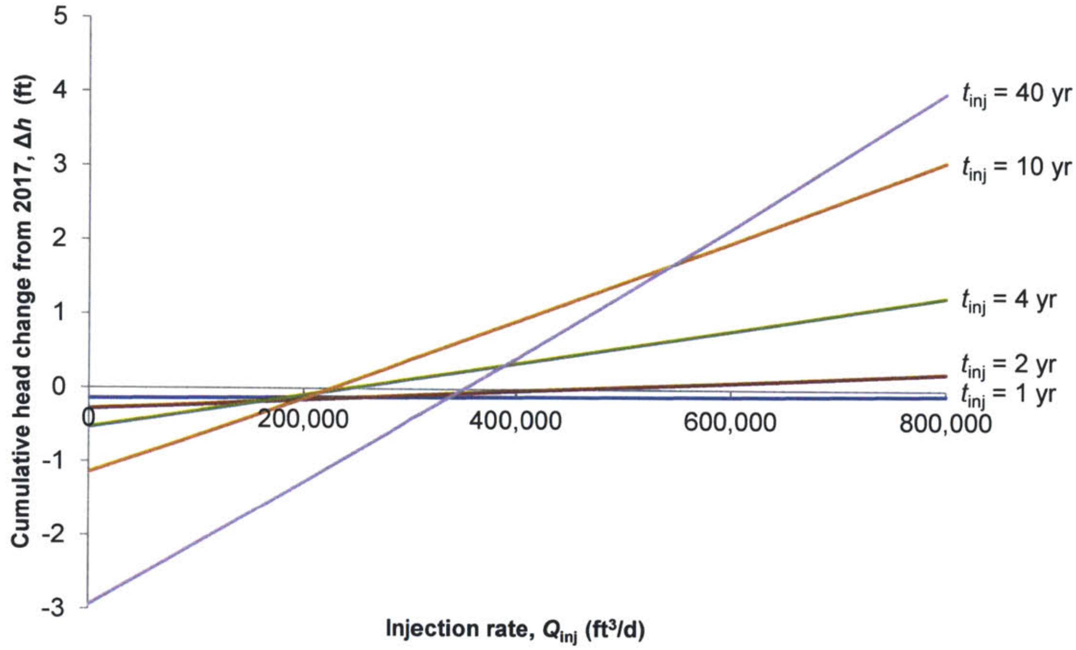

Figure 18: Simulated cumulative hydraulic-head change in El Dorado cone of depression (model cell 193, 64, 2) vs. injection rate for injection at Location 3.

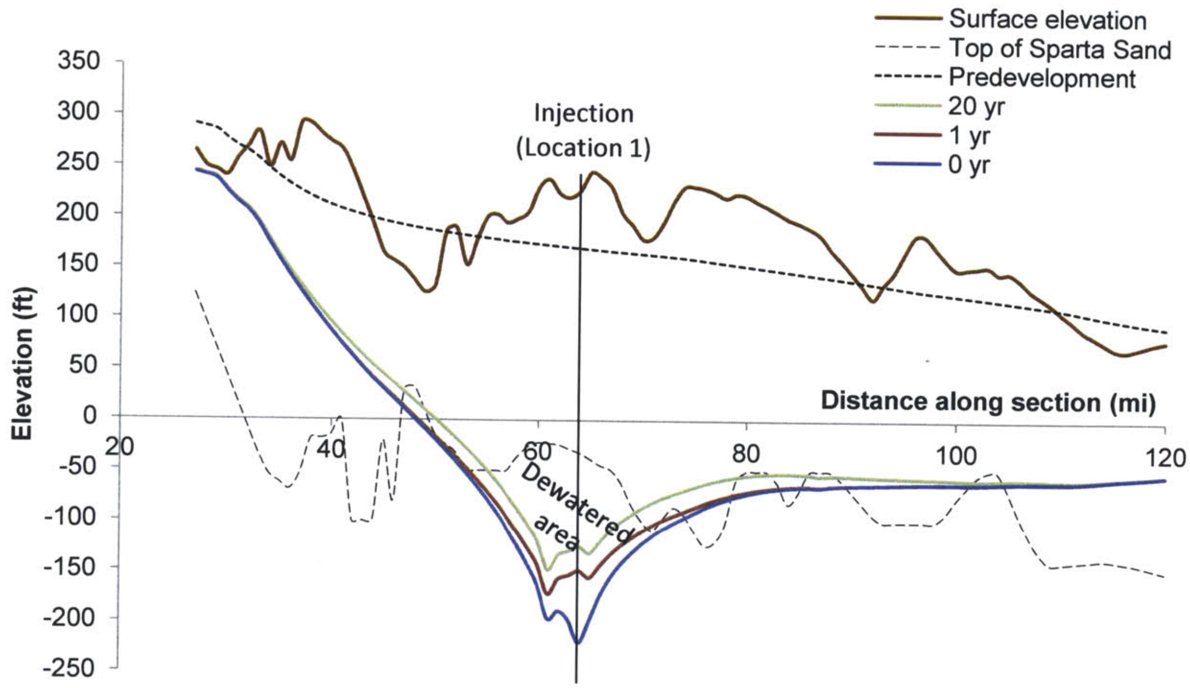

Figure 19: Simulated potentiometric-surface profile for artificial recharge (or reduction of withdrawals) of 3.0 MGD (400,000 ft^3/d) at Location 1.

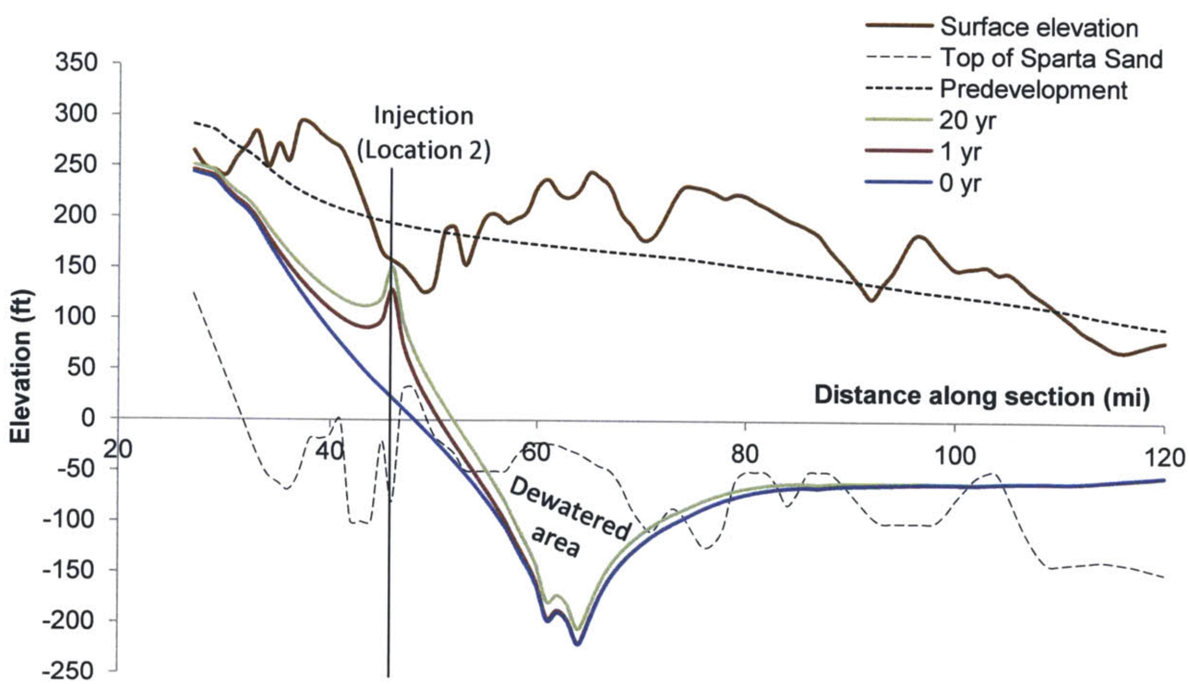

Figure 20: Simulated potentiometric-surface profile for artificial recharge of 3.0 MGD (400,000 ft^3/d) at Location 2.

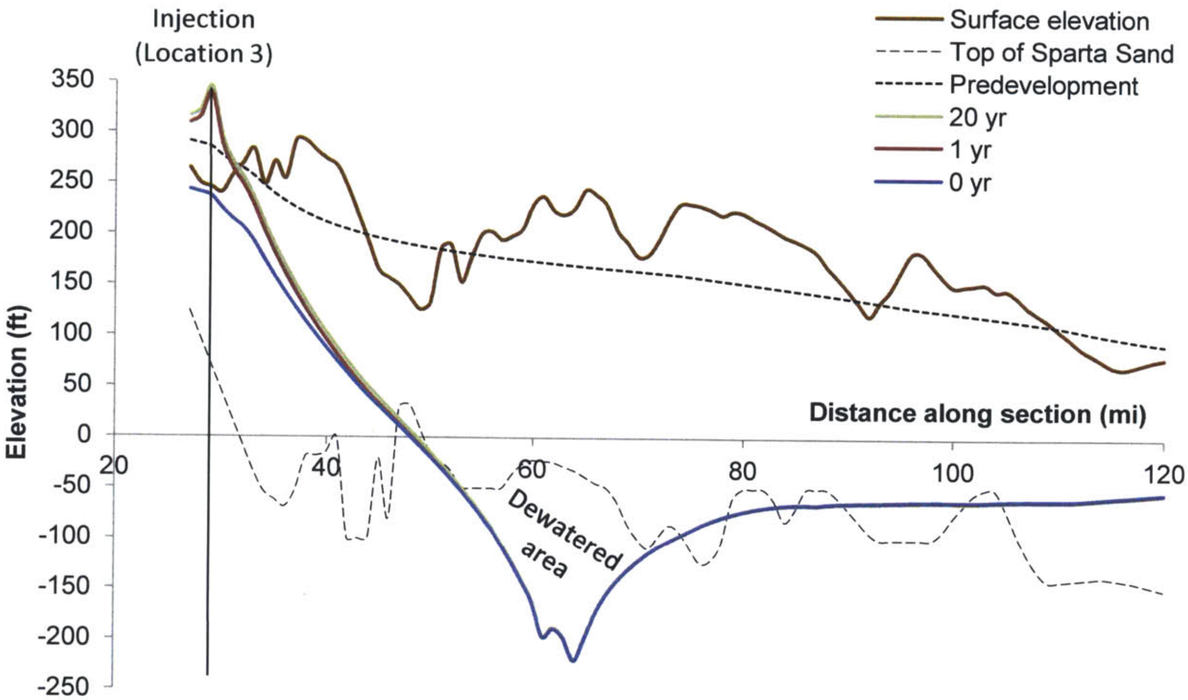

Figure 21: Simulated potentiometric-surface profile for artificial recharge of 3.0 MGD (400,000 ft^3/d) at Location 3.

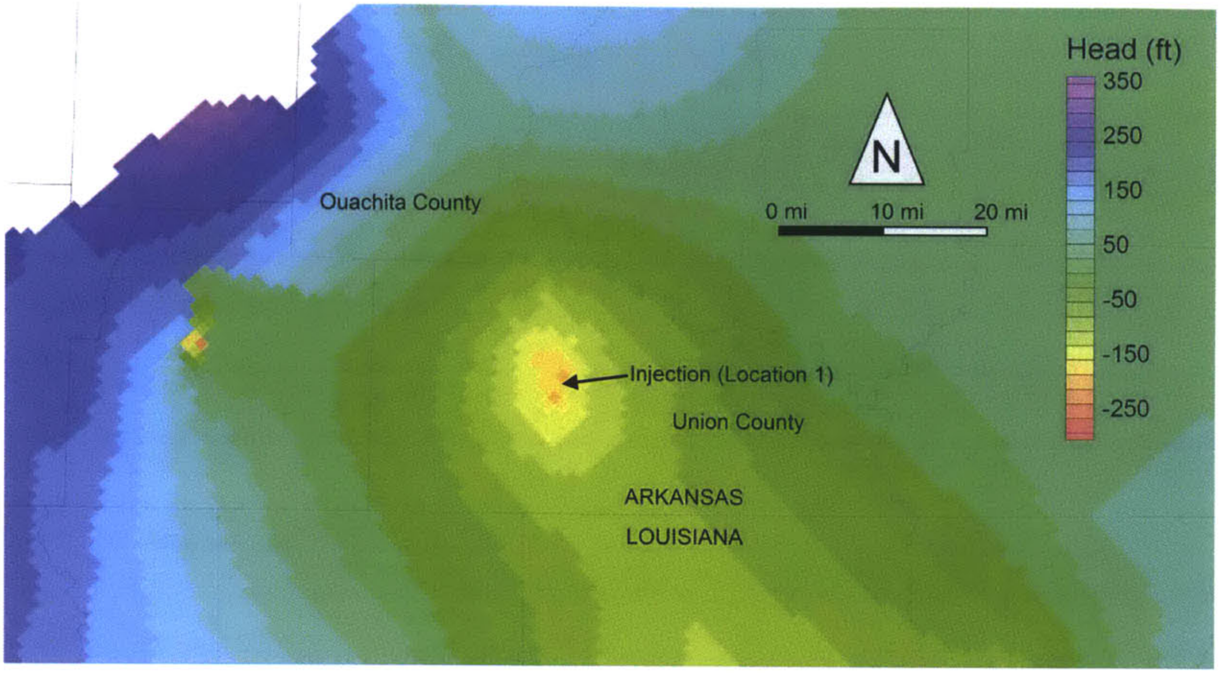

Figure 22: Simulated 2037 potentiometric surface after 20 yr of artificial recharge (or reduction of withdrawals) of 3.0 MGD (400,000 ft^3/d) at Location 1.

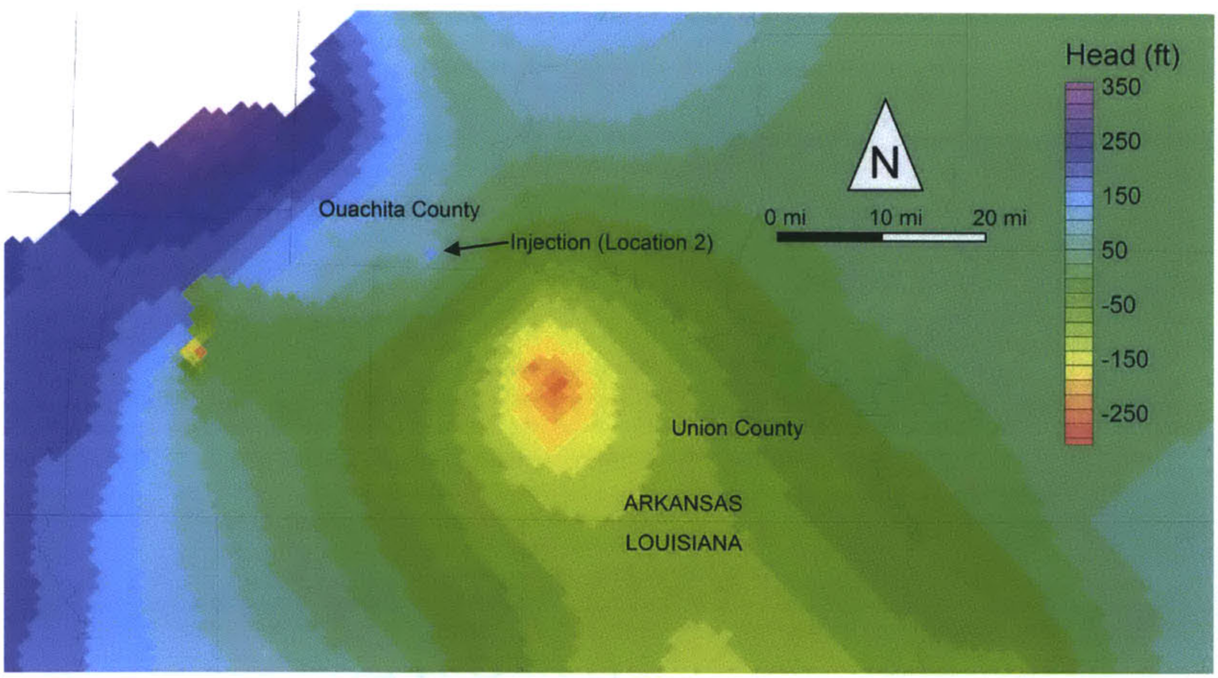

Figure 23: Simulated 2037 potentiometric surface after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at Location 2.

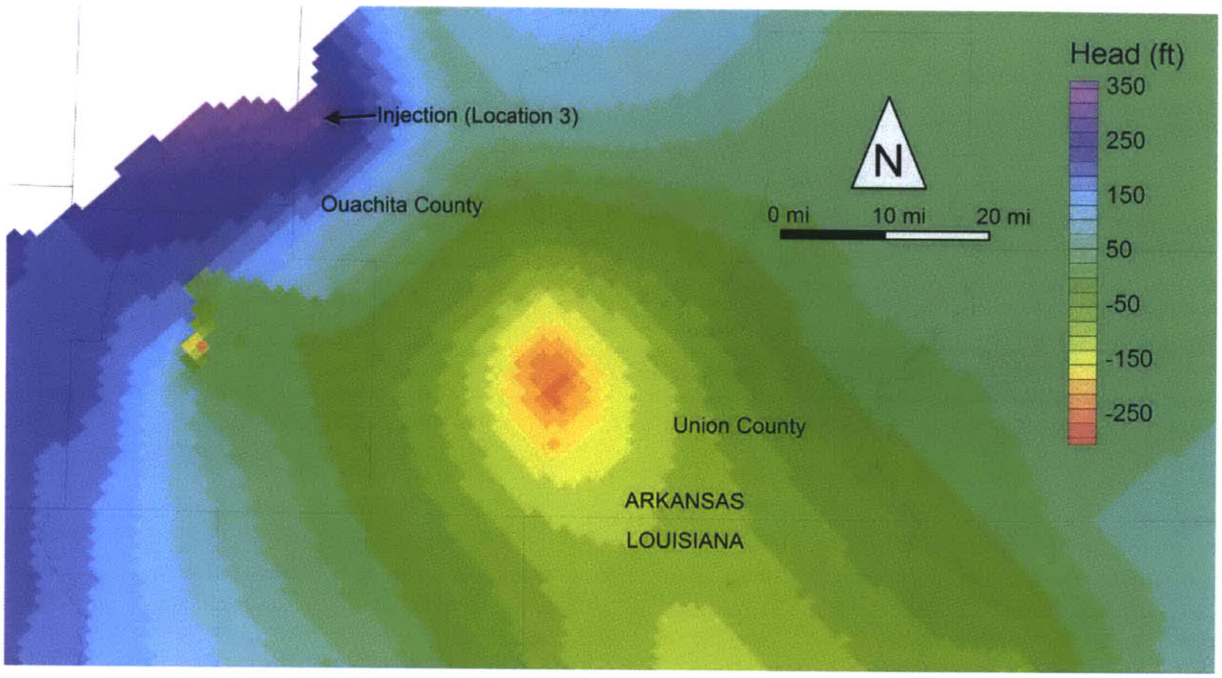

Figure 24: Simulated 2037 potentiometric surface after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at Location 3.

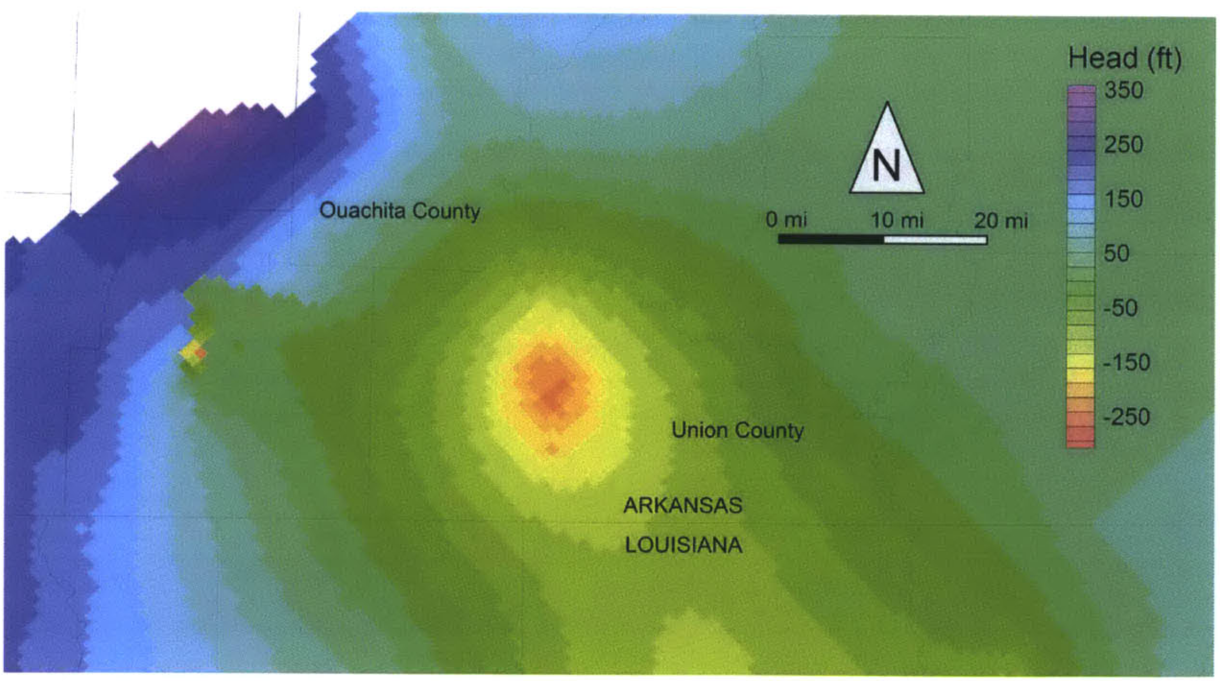

Figure 25: Simulated 2037 potentiometric surface (no artificial recharge).

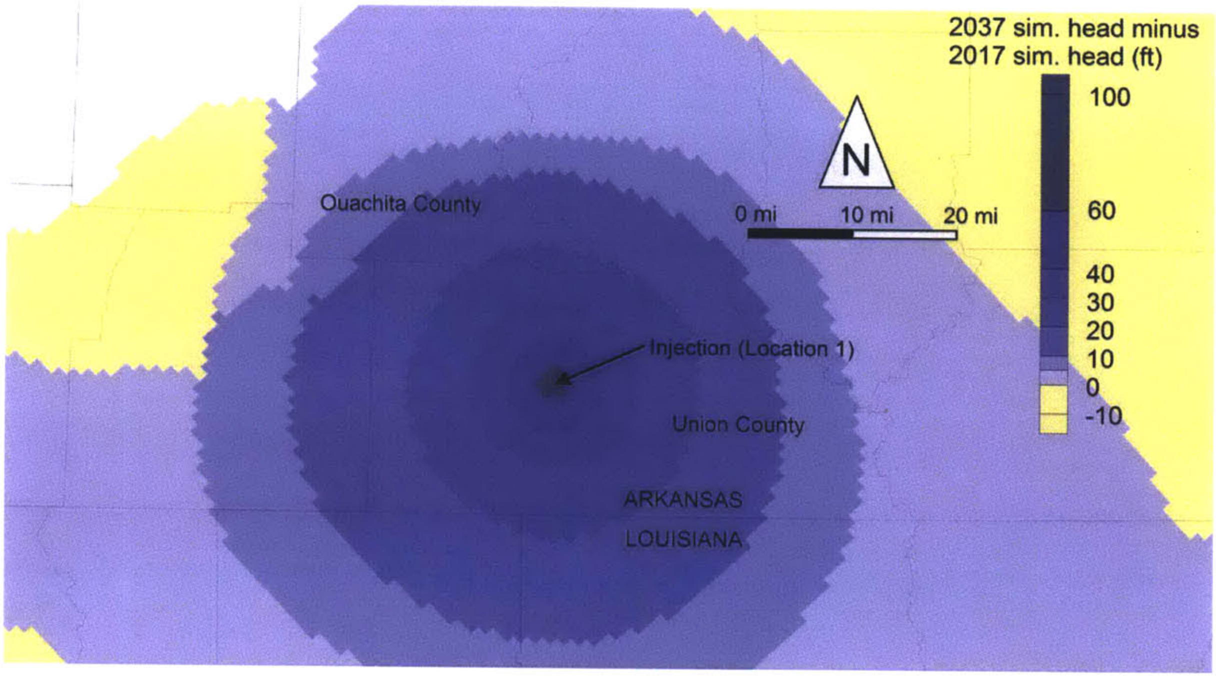

Figure 26: Simulated change in hydraulic heads (2037 minus 2017) after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at Location 1.

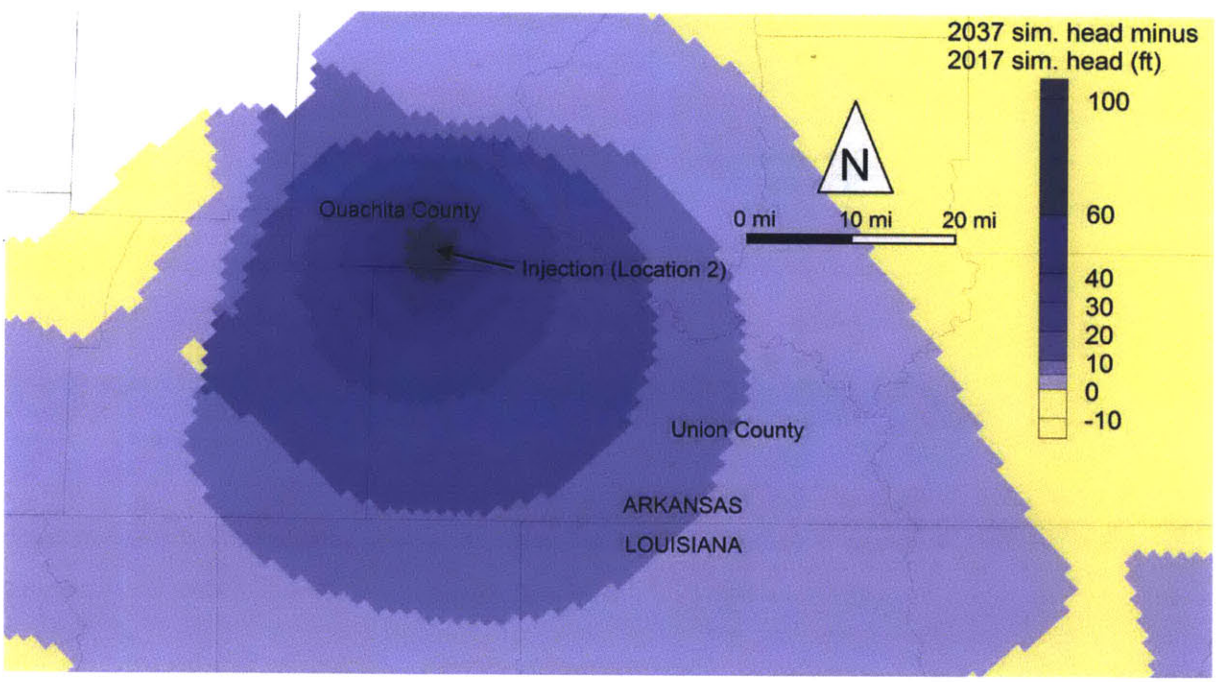

Figure 27: Simulated change in hydraulic heads (2037 minus 2017) after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at Location 2.

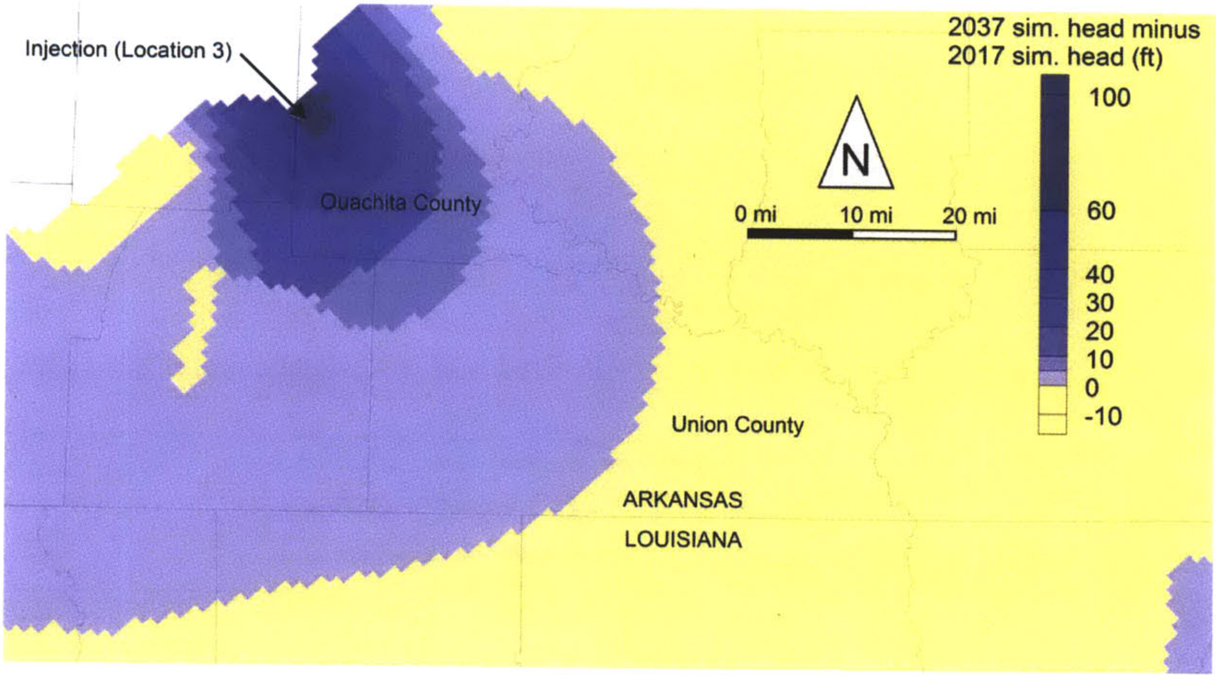

Figure 28: Simulated change in hydraulic heads (2037 minus 2017) after 20 yr of artificial recharge at 3.0 MGD (400,000 ft^3/d) at Location 3.

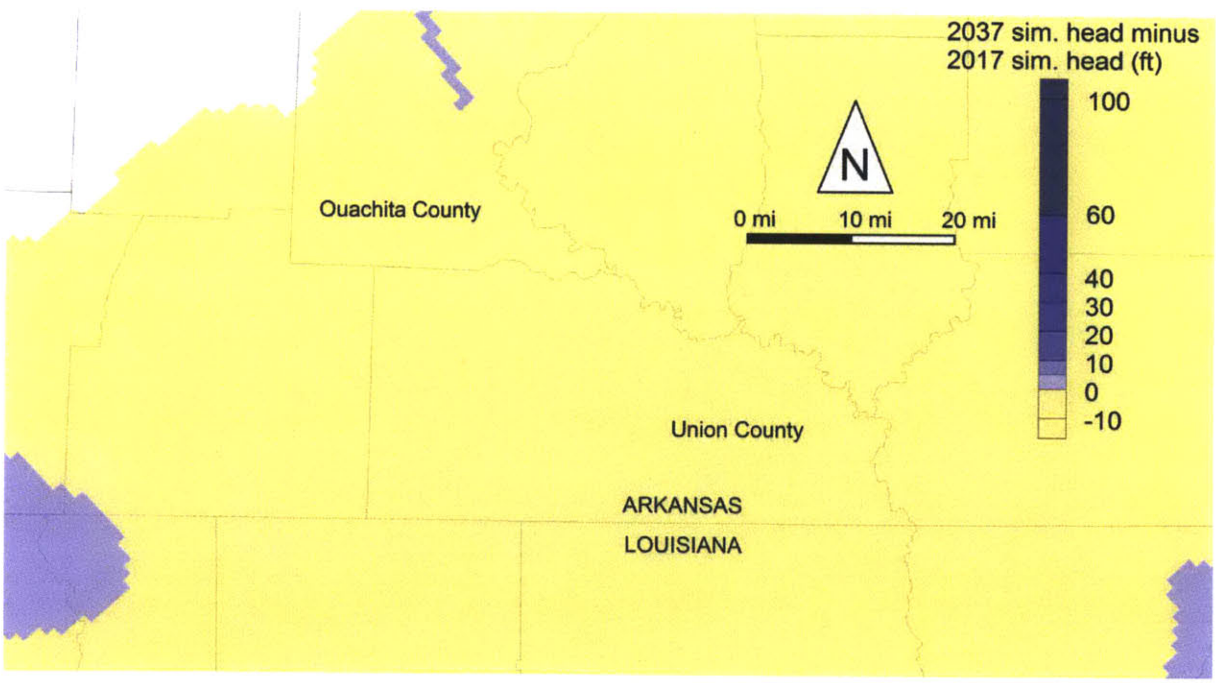

Figure 29: Simulated change in hydraulic heads (2037 minus 2017), no artificial recharge.

Discussion of MODFLOW Results

It is apparent from Figure 12 that aquifer development has significantly changed the potentiometric surface, especially in the section depicted. Drawdown in the cone of depression is on the order of 200 ft. Notice the dewatered area where hydraulic heads have fallen below the top of the Sparta Sand, creating unconfined (dewatered) conditions. Based on recharge parameters defined in the model and by our own understanding of the local aquifer geology, we had expected that the western portion of the Sparta aquifer in the model was unconfined. However, hydraulic heads defined in the model are higher than the top of the Sparta Sand in this area, suggesting confined conditions up to the model boundary as in Figure 12. This discrepancy may be due to our own interpretation of aquifer geology or undocumented assumptions inherent in the model.

In Figures 13–15 we observe the patterns of hydraulic head over time. All three scenarios exhibit the same general shape, though slopes and magnitudes vary. At Location 1, which is coincident with the critical area, artificial recharge (or reduction of withdrawals) causes heads to rise sharply and quickly. Most of the improvement occurs in the first few years, with minimal incremental benefit thereafter. With an injection rate of 3.0 MGD (400,000 ft^3/d), the head increases by 71 ft after 1 yr, and by 92 ft after 10 yr. For injection at Location 2 the head improvements in the critical area are lower and take longer to realize. Most of the improvement occurs within 20 yr. Heads increase by 1 ft after 1 yr, and by 13 ft after 10 yr with an injection rate of 3.0 MGD (400,000 ft^3/d). Simulations of artificial recharge at Location 3 suggest that due to the distance and extent of the aquifer formation, head improvements in the critical area are minimal, even with substantial fluxes. Heads do not increase below injection rates of 1.5 MGD (200,000 ft^3/d). With injection of 3.0 MGD (400,000 ft^3/d), the maximum head change is less than 1 ft and declines after 15 yr.

Comparing Figures 19–21, injection at Location 1 most directly raises hydraulic heads in the critical area (being at the same location). This repressurizes the aquifer somewhat and observable effects also occur upgradient and downgradient. With injection farther from the critical area, i.e., at Locations 2 and 3 (Figures 20 and 21), the effects on downgradient hydraulic heads are less evident. Injection at Location 2 contributes to some head increase in the critical area, but a groundwater mound or pressure mound—an inverse cone of depression—develops at the injection location. Injection at Location 3 has almost no effect on hydraulic heads in the critical area and similarly develops a groundwater mound around the injection location, which in this case exceeds the simulated predevelopment hydraulic heads Figures 23 and 24 also indicate these aberrations in the natural potentiometric surface at Locations 2 and 3. Figures 27 and 28 show similar patterns of the pressure mounds that form in each location.

Comparing our injection results with the surface-recharge results of Hays (2001), we find that injection (or reduction of withdrawals) in El Dorado (Location 1) has a more profound and more immediate effect on hydraulic heads in the same area. The 25-ft head increase in 7 yr reported by Hays for a canal system recharging approximately 224 MGD (30,000,000 ft^3/d) can be achieved within 1 yr with an injection rate of 1.5 MGD (200,000 ft^3/d) at Location 1. However, since injection has a limited area of influence, improvements in more distant areas are minimal. Hays's model, in which the recharge was distributed over a large area and the actual volume of recharged water was much higher, showed increases of 5 ft or more across 15 counties.

Conclusions and Recommendations

Artificial recharge by injection in the Sparta aquifer is impractical. While injection would increase hydraulic heads locally, injection outside of the critical area (El Dorado) would not satisfactorily raise hydraulic heads in the critical area. Since groundwater withdrawals are already concentrated in the El Dorado vicinity, reducing or substituting withdrawals would have the same effect as injection, but without the aforementioned costs and challenges of regulation, treatment, geochemical compatibility, implementation, and operation.

We therefore recommend continued use and expansion of the Ouachita River Alternative Water Supply Project to offset groundwater withdrawals from the Sparta aquifer. The project has already contributed to significant aquifer recovery in Union County and offers the highest potential for further improvements. Since Sparta groundwater is recognized for its high quality, it is a valuable resource that should be prioritized for certain uses that most directly benefit from that high quality. Until the production capacity of the Ouachita River Alternative Water Supply Project is reached, continued and expanded conjunctive use is the most obvious option for Union County.

As of 2012, the project is only using about 11 MGD (1,470,000 ft^3/d) of its 32 MGD (4,280,000 ft^3/d) capacity, leaving 21 MGD (2,810,000 ft^3/d) available for new or expanding industrial users (Robert Reynolds, pers. comm., 28 Feb. 2013). The current capacity is limited by the clarification facility; a duplicate treatment train would bring the capacity to 64 MGD (8,560,000 ft^3/d). This is comparable to the intake structure's capacity and the permitted peak-day withdrawal rate of 65 MGD (8,690,000 ft^3/d). Additional storage and conveyance infrastructure may be needed if the operation expands. There is existing excess capacity in the project, as well as the potential to increase the capacity if needed. While conservation has already helped reduce demands, it may be possible to develop new conservation methods and technologies and/or innovate on water efficiency in industrial and domestic applications. For the time being, conjunctive use of surface- and groundwater appears to be an effective and sustainable water-management strategy in Union County that should continue.

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Appendix A: Arkansas Field Notes

Introduction

As part of this project, David E. Langseth, Joyce Ni Zhu, and Robert B. Sowby visited Arkansas from January 11 to 15, 2013. Our technical purposes included meeting with experts, touring water facilities, learning about water use, and understanding local geology and hydrogeology. Here we have outlined the personnel, activities, discussions, and notes relevant to our trip.

Visit to U.S. Geological Survey (USGS) Arkansas Water Science Center (AWSC) Office, Little Rock

Date

- January 11, 2013

AWSC General Information

- AWSC organization chart: http://ar.water.usgs.gov/AROrgChart.pdf
- Office address: 401 Hardin Road, Little Rock, AR 72211

Personnel

- John Czarnecki, USGS (jczarnec@usgs.gov)
- Tony Schrader, USGS, hydrologist, data manager (tpschrad@usgs.gov)
- David Freiwald, USGS, AWSC Director
- Doug Hanson (via phone), AGS (doug.hanson@arkansas.gov)

Notes

- John described three sand layers (White, Green, El Dorado) in Sparta aquifer. In Union County, Green Sand and El Dorado Sand are most productive units. Green Sand is above El Dorado Sand (see Hays, 2000; Yeatts, 2004). Robert Reynolds confirmed that Green Sand in on top, but said that White Sand is synonymous with El Dorado Sand
- John mentioned possible unconfined or perched conditions within these layers; conditions unknown. John received funding approval for a study that will investigate this issue further.
- Doug gave input on outcrop areas in Camden with coordinates
- El Dorado sand is primary producing layer in Union County
- Tony showed samples of Green Sand and White Sand (no El Dorado Sand sample available)
- Tony showed us where to find data on USGS Groundwater Watch website; Sparta Recovery Network has its own section

- Sparta dropped ~350 ft since pre-development; recovered as much as ~60 ft in last 8 years with alternative supply project (measurements at Monsanto well); still long way to go
- Pre-1970s data dubious for some locations—only approximate water levels
- Some wells in eastern Arkansas are double screened in both Sparta aquifer and alluvial aquifer—gives inconsistent picture of water levels
- Limited state regulation on pumping
- State can declare "critical groundwater area"—first step toward regulation
- Union County (declared critical groundwater area) needed to reduce to 28% of previous water use

Geology Field Trip, Ouachita County

Date

- January 12, 2013

Personnel

- Robert Reynolds, President, Union County Water Conservation Board (UCWCB; also an engineer, geologist, driller, and president of Shuler Drilling Company, Inc. (robertreynolds@suddenlink.net)
- Sherrel Johnson, UCWCB administrator (sherrelj@suddenlink.net)
- Nancy Whitmore, geology instructor at South Arkansas Community College (nawhitmore@suddenlink.net or nwhitmore@southark.edu)
- UCWCB web site is at http://argis.ualr.edu/website/unionCoGraph/index.asp or http://www.ucwcb.org

Sites and notes

- See accompanying map entitled "Geology Field Trip" (Figure A16)
- Site 1: Exposure on south side of Bradley Ferry Road (County Road 58) near US-79/US-278
  - See Figures A3–A8
  - 33°34'22.18" N, 92°48'45.91" W
  - Sparta Sand
    - Fine grain, little clay, light color
    - About 5 ft exposed
    - Some ferric "cement" at this site—orange color and more durable
  - Cook Mountain formation
    - Clay confining unit above Sparta sand

            - Dark color
            - Occasional lignite
    - Nancy brings geology students here to look for fossils
    - This location was one of Doug Hanson's recommendations
- Site 2: Exposure behind businesses west of US-79B, north of Camden Walmart
    - 33°34'25.48" N, 92°50'13.56" W
    - Tall cut into hill showing two distinct layers
    - This location was one of Doug Hanson's recommendations
- Site 3: Recently excavated pond off Highway 24
    - See figure A9
    - 33°36'24.29" N, 92°54'48.26" W
    - Clay
- Site 4: Near Poison Spring State Park
    - 33°38'21.28" N, 93° 0'22.08" W
    - Wilcox Sand according to state geologic map by Arkansas Geological Survey—not part of Sparta—see Figure A10

Tour of Ouachita River Alternative Water Supply Project, Union County

Date

- January 12, 2013

Personnel

- Same as previous

Notes and sites

- Project overview
    - Built early 2000s to serve power plant cooling and offset groundwater stress
    - Design by Burns and McDonnell of Kansas City
    - Wide public support; project was as much a social success as a technical solution
    - Funded by temporary countywide sales-tax increase in Union County
    - Entegra power plant helped fund project
    - Board sells water at $0.82/1000 gal (discounted to $0.77/1000 gal for Entegra)
- Intake structure on Ouachita River
    - See Figure A11
    - 65 MGD capacity (100 cfs)
    - 2012 average intake: 10.7 MGD

- Lots of capacity still available
- River discharge was approx. 4,000–6,000 cfs at time of visit (estimate based on Ouachita River downstream, subtracting tributary flows in between where available). Considerable uncertainty in this figure.
- Disinfection applied here (see Figure A12)
- Pumped to clarification facility

- Water clarification facility
  - See Figure A13
  - 32 MGD current capacity
  - Can expand to 64 MGD ("mirror" layout)
  - 3 process trains (2 running at time of visit)
  - On-site laboratory for quality monitoring (see Figures A14 and A15)
  - Finished water delivered to clients from here
- Entegra power plant
  - Largest UCWCB water client
  - 2200 MW power production
  - Methane combustion (delivered by pipeline)
  - Uses ~4000 gpm (5.8 MGD, 18 cfs) for cooling (evaporates)
  - Entegra personnel maintain water facilities

Discussion with Robert Reynolds

Date

- January 12, 2013

Notes

- Union County needed to reduce to 28% of previous use. Conservation cut ~20%. Most reduction of groundwater withdrawals would come from alternative supply.
- Sparta recovered 60 ft in past 8 years. Would like to see 30 ft recovery in next 8 years.
- USGS ran transmissivity and storage tests in February 2012. Results were identical with 1999 and 1949 tests—no compaction or consolidation has occurred; storage volume was unaffected by low water levels. (Big relief.)
- Extra capacity exists in the alternative-supply facilities. This will allow industries to expand operations or for more industries to connect.
- If groundwater problem worsens, next round of industries will be encouraged to convert to Ouachita River water. However, exact future steps are unclear.
- Ouachita River water, when clarified, turns out to be better for many industries because its mineral content is lower than Sparta groundwater.

- "No reason not to" convert industries from Sparta water to Ouachita River water.
- Would rather see Sparta water used for drinking water because of high quality.

Eastern Arkansas and Mississippi

Date

- January 13, 2013

Notes

- Nontechnical tour
- El Dorado, Greenville, Helena, Little Rock
- Rice fields, forests, bayous, Mississippi River, levees, bridges
- Considerable off-road inundation following rainstorm

Visit with Brian Clark at USGS Field Office, Fayetteville

Date

- January 14, 2013

Personnel

- Brian Clark, USGS (brclark@usgs.gov)

Notes

- Availability of USGS groundwater models
  - New MERAS model still in development—could be several months before publication
  - Model used for Sparta conjunctive use optimization study is still available. It is a much simpler model, focusing on the Sparta, rather than whole MERAS.
  - Conclusion: We will the use older model—simpler and smaller though outdated
  - Brian provided files for USGS MODFLOW model (from 2003) of Sparta aquifer
- Sparta layers—green, white, El Dorado
- Brian showed us some resistivity logs

Photos

Figure A1: Joyce Zhu and Rob Sowby at USGS office in Little Rock. (Photo by David E. Langseth)

Figure A2: John Czarnecki (background), Joyce Zhu, and Tony Schrader at USGS office in Little Rock. (Photo by Robert B. Sowby)

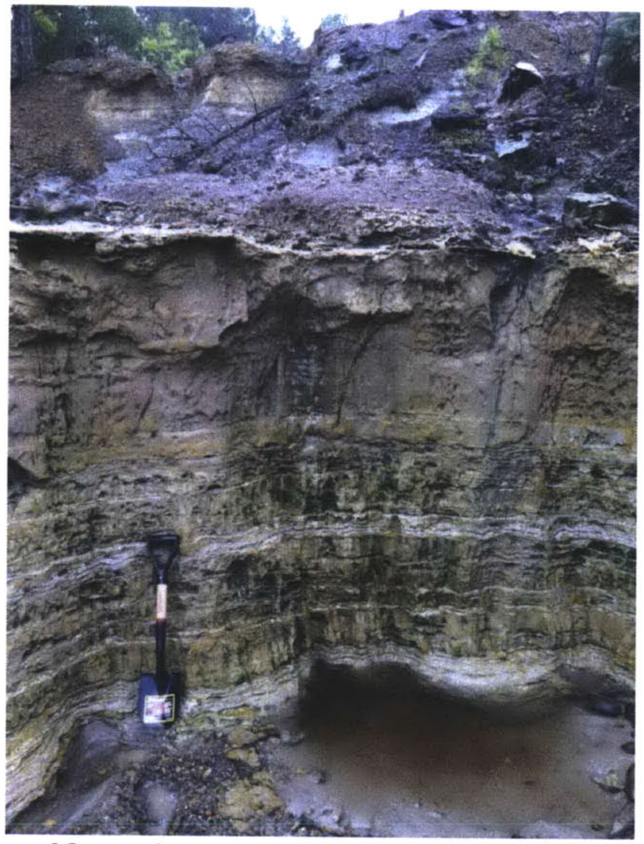

Figure A3: Top portion of Sparta Sand (foreground) with Cook Mountain confining unit above (background), Site 1. (Photo by Robert B. Sowby)

Figure A4: Robert Reynolds and Sherrel Johnson examine formations at Site 1. (Photo by Joyce Ni Zhu)

Figure A5: David Langseth samples Sparta Sand at Site 1. (Photo by Joyce Ni Zhu)

Figure A6: Cook Mountain clay at Site 1. (Photo by Joyce Ni Zhu)

Figure A7: Sparta Sand (foreground) with Cook Mountain clay above (background), Site 1.
(Photo by Robert B. Sowby)

Figure A8: Nancy Whitmore and Rob Sowby examine rock specimens at Site 1.
(Photo by Joyce Ni Zhu)

Figure A9: Rob Sowby, Robert Reynolds, and David Langseth at Site 3 (pond cut). (Photo by Sherrel Johnson)

Figure A10: Wilcox Sand at Site 4. (Photo by Joyce Ni Zhu)

Figure A11: Ouachita River intake and pumping facility. (Photo by John Czarnecki)

Figure A12: Sodium hypochlorite tank at alternative-supply intake. (Photo by Joyce Ni Zhu)

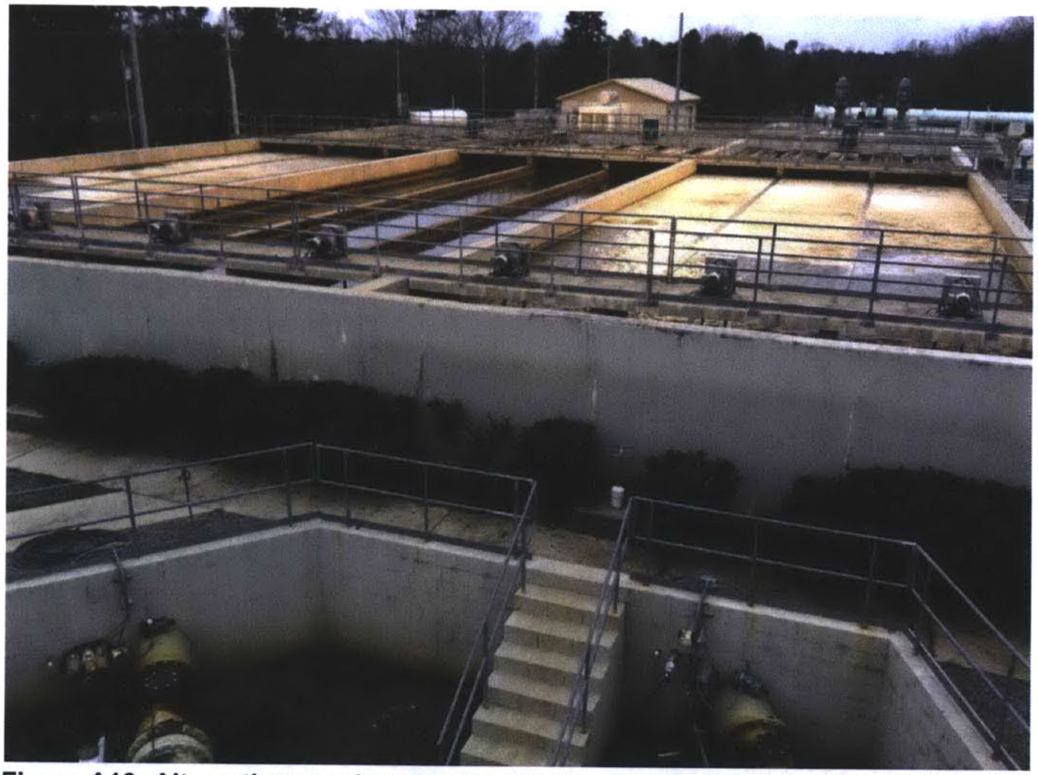

Figure A13: Alternative supply water-clarification facility. (Photo by Robert B. Sowby)

Figure A14: Water-quality testing equipment at clarification facility. (Photo by Joyce Ni Zhu)

Figure A15: Raw water (left) and clarified water. (Photo by Joyce Ni Zhu)

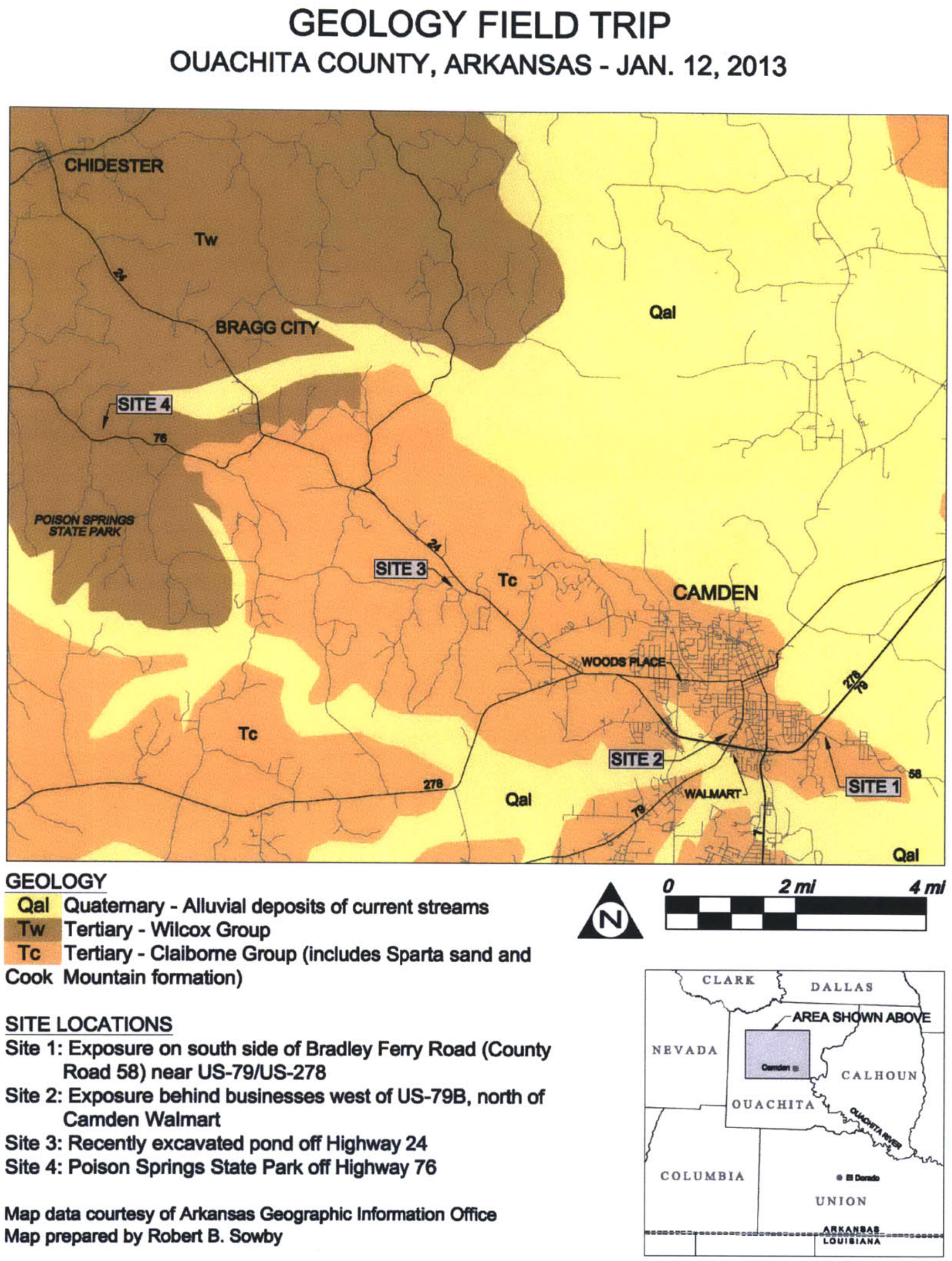

Figure A16: Map of geology field trip.

Appendix B: Surfacewater-Availability Analysis

Introduction

This appendix describes availability of surfacewaters in and near Union County, Arkansas. The Ouachita River is discussed specifically in Appendix C. The purpose is to provide a preliminary assessment of these waters and their potential to augment Union County's water supply, which until recently has relied solely on groundwater from the Sparta aquifer.

Data Sources

The U.S. Geological Survey (USGS) has maintained several stream gages on streams in and near Union County. Data were analyzed for 6 sites, as published in the USGS's National Water Information System (NWIS). All data were obtained directly from NWIS as monthly means (the mean of all daily flow observations in each month). See Table B1 and Figure B1.

Table B1: USGS Stream Gages near Union County

Site ID	Site Name	Data Type	Years of Record	Number of Observations
USGS 07362100	Smackover Creek near Smackover, AR	Monthly mean	1961–2012	612
USGS 07362000	Ouachita River at Camden, AR	Monthly mean	1928–2011	983
USGS 07362500	Moro Creek near Fordyce, AR	Monthly mean	1951–2012	522
USGS 07363500	Saline River near Rye, AR	Monthly mean	1937–2012	897
USGS 07365800	Cornie Bayou near Three Creeks	Monthly mean	1956–1987	378
USGS 07365900	Three Creeks near Three Creeks, Ark.	Monthly mean	1956–1971	174

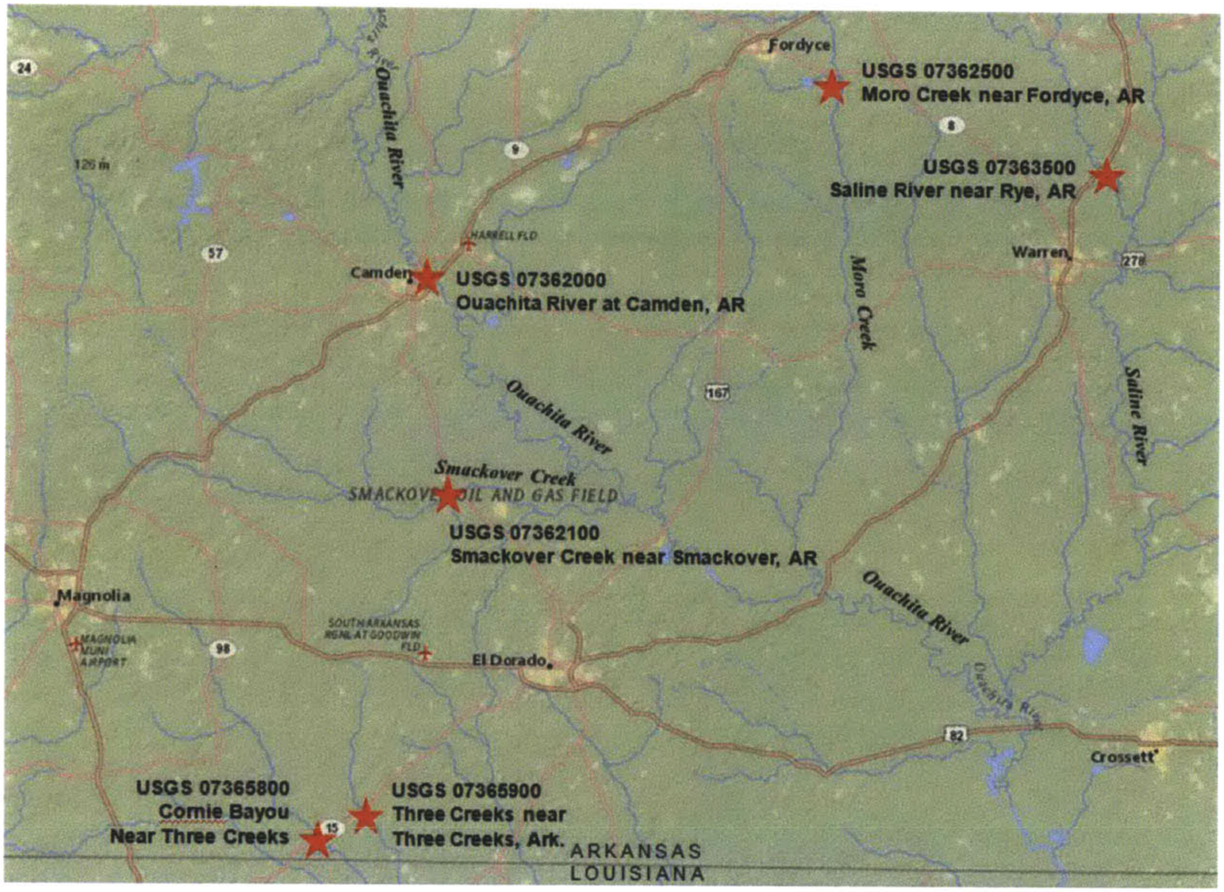

Figure B1: Locations USGS stream gages near Union County. (Basemap from Esri and National Geographic)

Flow-Duration Curves

To analyze the streamflow data we applied the method of the flow-duration curve (FDC) or flow-duration analysis. FDCs establish a relationship between flow magnitudes and flow frequencies over time. An FDC is defined as follows (Searcy 1959):

> The flow-duration curve is a cumulative frequency curve that shows the percent of time which specified discharges were equaled or exceeded in a given period. It combines in one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurence [sic]. If the period upon which the curve is based represents the long-term flow of a stream, the curve may be used to predict the distribution of future flows for water-power, water-supply, and pollution studies.

To produce an FDC, flow data are arranged in decreasing order of magnitude. The data are ranked, with 1 representing the highest flow, and each observation is assigned an exceedance probability based on its rank and the number of observations. The exceedance probability represents the probability that the flow will be exceeded, based on the historical record, and is computed as (EPA 2011):

$$P = 100\left(\frac{R}{N+1}\right)$$

where P is the exceedance probability expressed as a percentage, R is the rank, and N is the number of observations. On the graph of an FDC, flows are plotted on the vertical axis while exceedance probability is plotted on the horizontal axis. The axes may be linear or logarithmic.

Using the monthly mean data described earlier, we developed FDCs for the 6 sites. Figure B2 shows the average monthly discharge for each of the 6 sites. Figures B3–B9 show the associated FDCs. On the FDCs, the vertical axes represent monthly mean discharge (logarithmic scale) and the horizontal axes represent the exceedance probability based on the monthly means. Note that the mean flow is not the same as the 50-percent exceedance flow. Relevant statistics are shown on each FDC. Table B2 summarizes the flow statistics in MGD and Table 3 summarizes the flow statistics in ft^3/s.

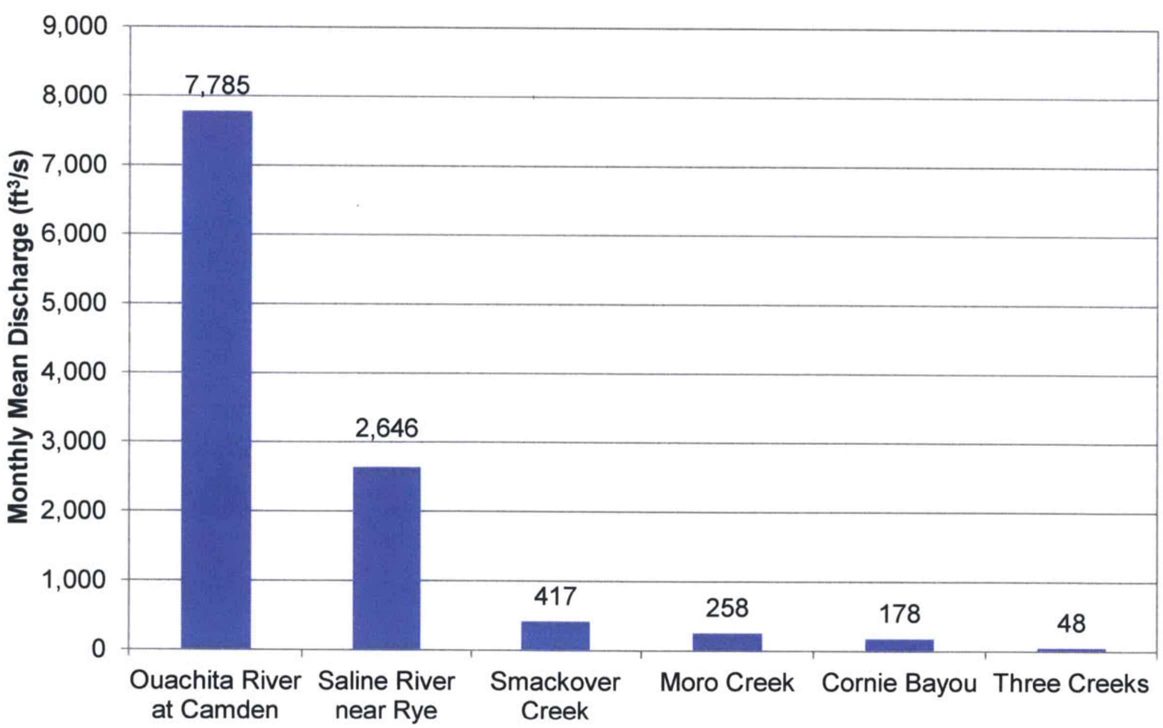

Figure B2: Mean discharge of several streams near Union County.

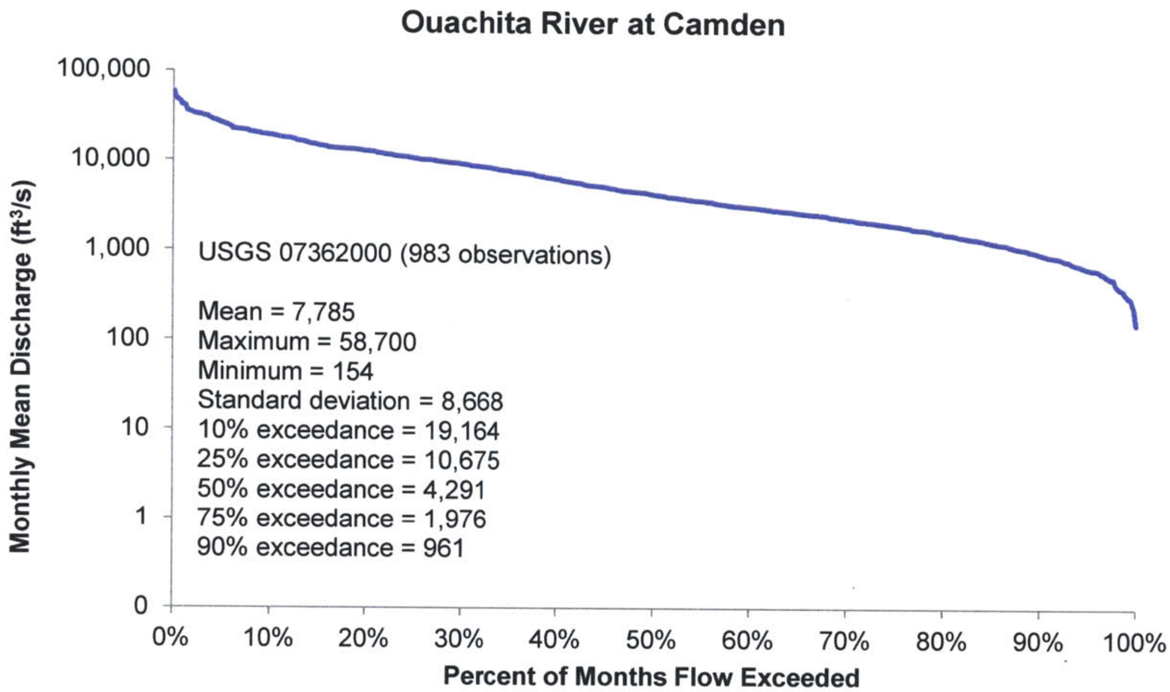

Figure B3: Flow-duration curve for Ouachita River at Camden.

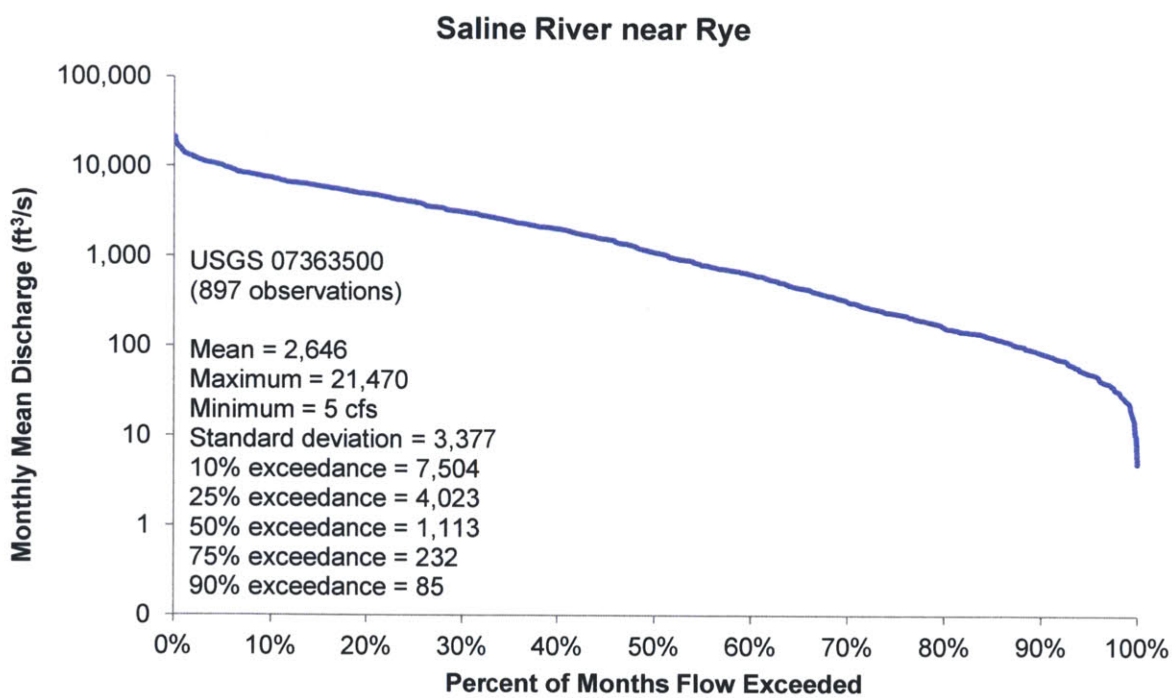

Figure B4: Flow-duration curve for Saline River near Rye.

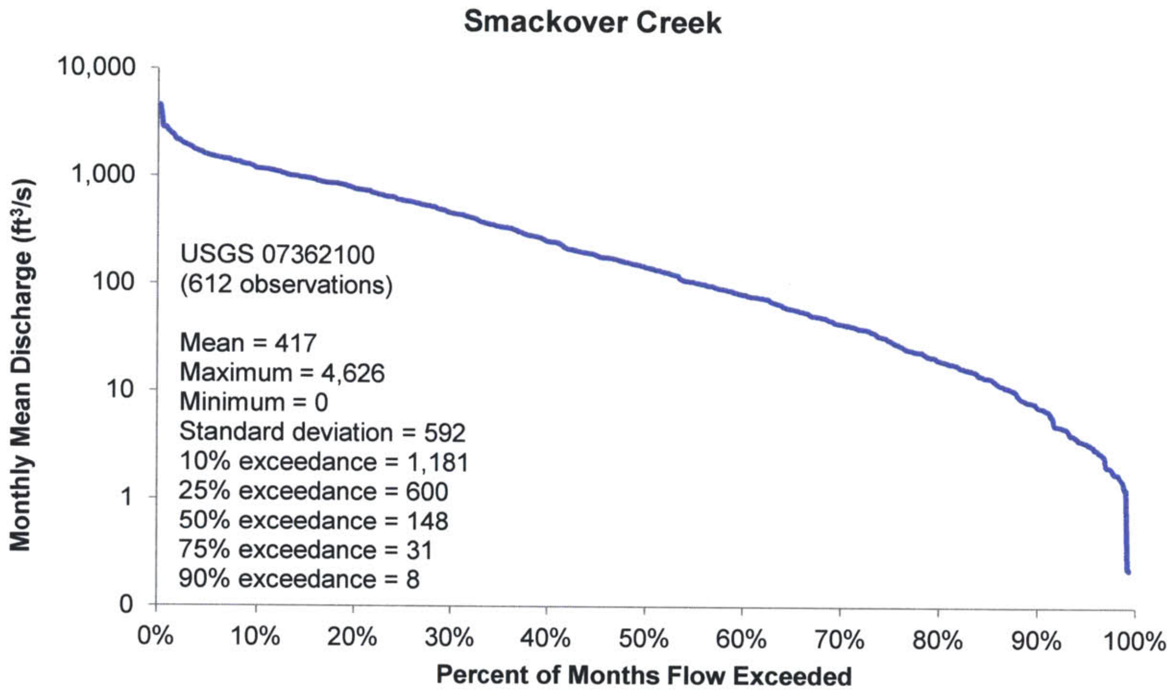

Figure B5: Flow-duration curve for Smackover Creek.

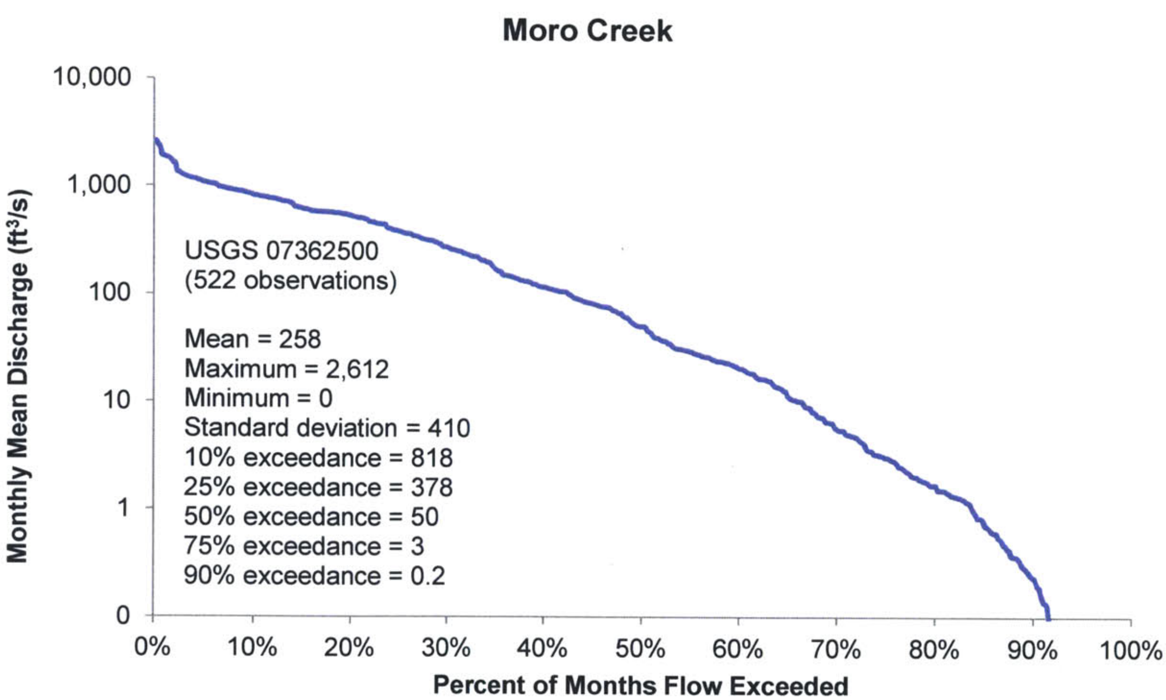

Figure B6: Flow-duration curve for Moro Creek.

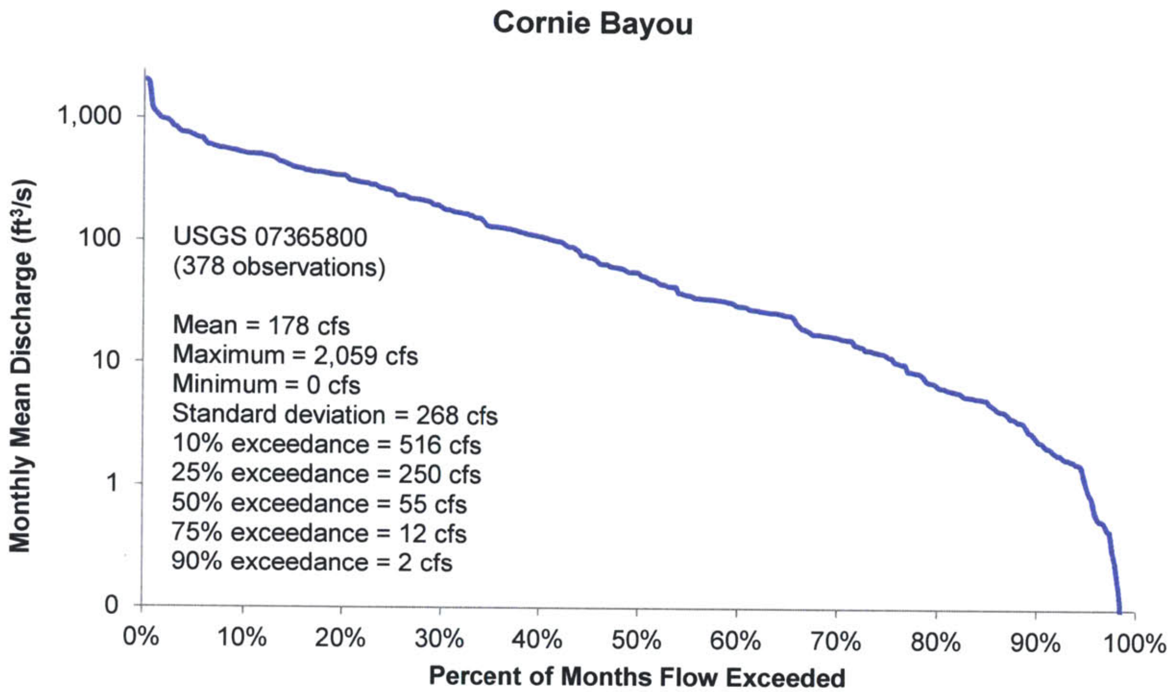

Figure B7: Flow-duration curve for Cornie Bayou.

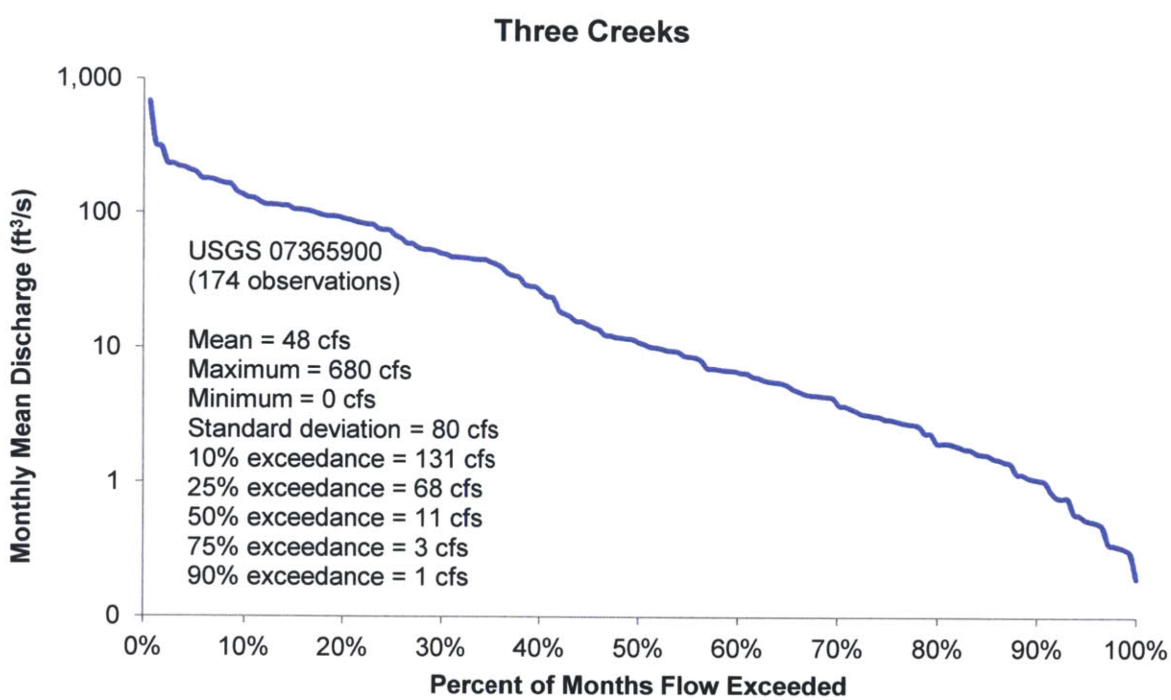

Figure B8: Flow-duration curve for Three Creeks.

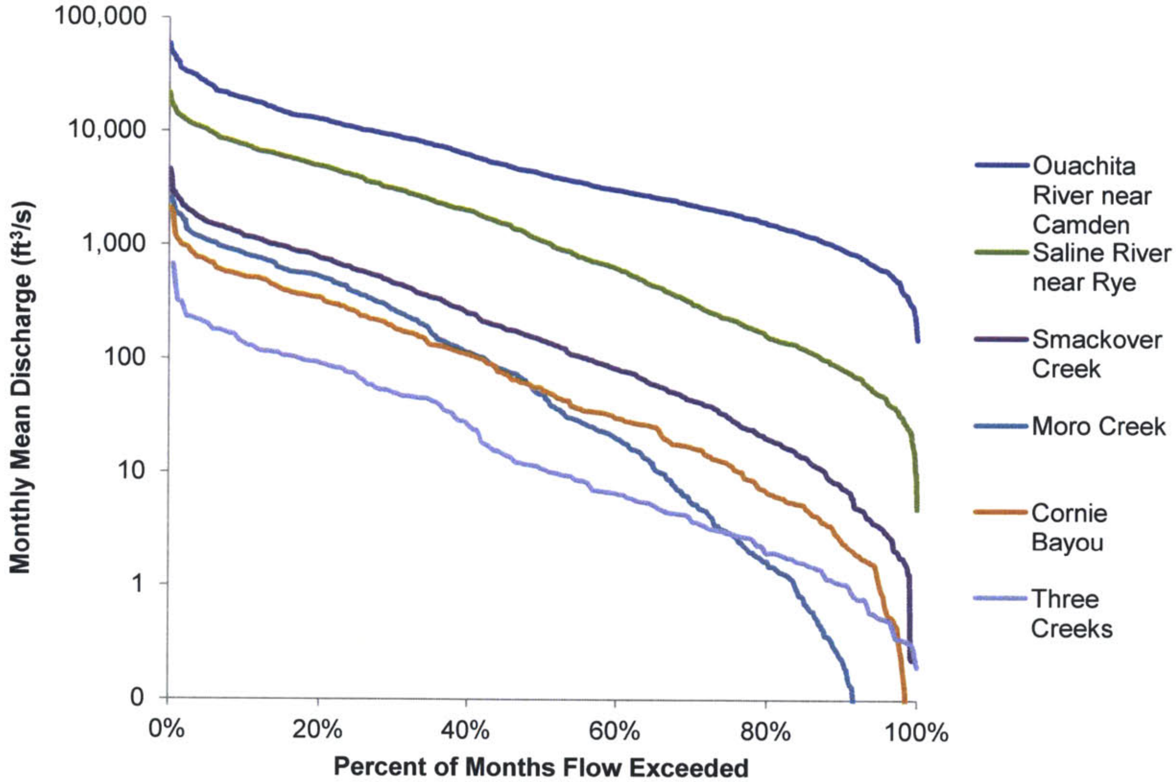

Figure B9: Flow-duration curves for six streams near Union County, Arkansas.

Table B2: Streamflow Statistics for Six Streams near Union County, Arkansas (MGD)

Statistic	Ouachita River at Camden	Saline River near Rye	Smack-over Creek	Moro Creek	Cornie Bayou	Three Creeks
Mean	5,031	1,710	270	167	115	31
Maximum	37,936	13,875	2,988	1,688	1,331	440
10% exceedance	12,385	4,850	763	529	334	84
25% exceedance	6,899	2,600	388	244	161	44
50% exceedance	2,773	719	96	32	36	7
75% exceedance	1,277	150	20	2	8	2
90% exceedance	621	55	5	0	2	1
Minimum	100	3	0	0	0	0
Std. deviation	5,602	2,182	382	265	173	52

Table B3: Streamflow Statistics for Six Streams near Union County, Arkansas (ft^3/s)

Statistic	Ouachita River at Camden	Saline River near Rye	Smack-over Creek	Moro Creek	Cornie Bayou	Three Creeks
Mean	7,785	2,646	417	258	178	48
Maximum	58,700	21,470	4,624	2,612	2,059	680
10% exceedance	19,164	7,504	1,181	818	516	131
25% exceedance	10,675	4,023	600	378	250	68
50% exceedance	4,291	1,113	148	50	55	11
75% exceedance	1,976	232	31	3	12	3
90% exceedance	961	85	8	0	2	1
Minimum	154	5	0	0	0	0
Std. deviation	8,668	3,377	592	410	268	80

Discussion and Conclusions

The FDCs presented in Figures B3–B8 have the same general shape one would expect for most streams, with high flows having low exceedance probabilities and low flows having high exceedance probabilities. In Figure B9, the difference in discharge magnitudes among the several sites is more apparent.

As is evident from the previous figures and table, the Ouachita River, which forms Union County's eastern and northern borders, represents the largest flux of surfacewater in the region. The Ouachita River is discussed in further detail in Appendix C. Its mean monthly flow exceeds 1,900 ft^3/s in 75 percent of the observations. The Ouachita River is the source of Union County's alternative water supply described earlier in the report. With the rare exception of low flows, the Ouachita River can continue to supply Union County's alternative water, even if the project expands. In rare cases where river flows are insufficient, industries may draw on groundwater from the Sparta aquifer.

Appendix C: Ouachita River Watershed Analysis

Introduction

The Ouachita River is Union County's largest surfacewater, as was discussed earlier in the report and also in Appendix B. This appendix focuses on the Ouachita River's watershed upstream of Union County and its seasonal water balance.

Watershed Characteristics

The Ouachita River system originates in the mountains of eastern Arkansas and flows east and south (Figure C1). Near Jonesville, Louisiana, it joins the Tensas River to form the Black River. Its main channel is 548 mi long. The Ouachita River watershed upstream of Union County is shown in Figure C2. Descriptive characteristics were collected from several data sources and are summarized in Table C1.

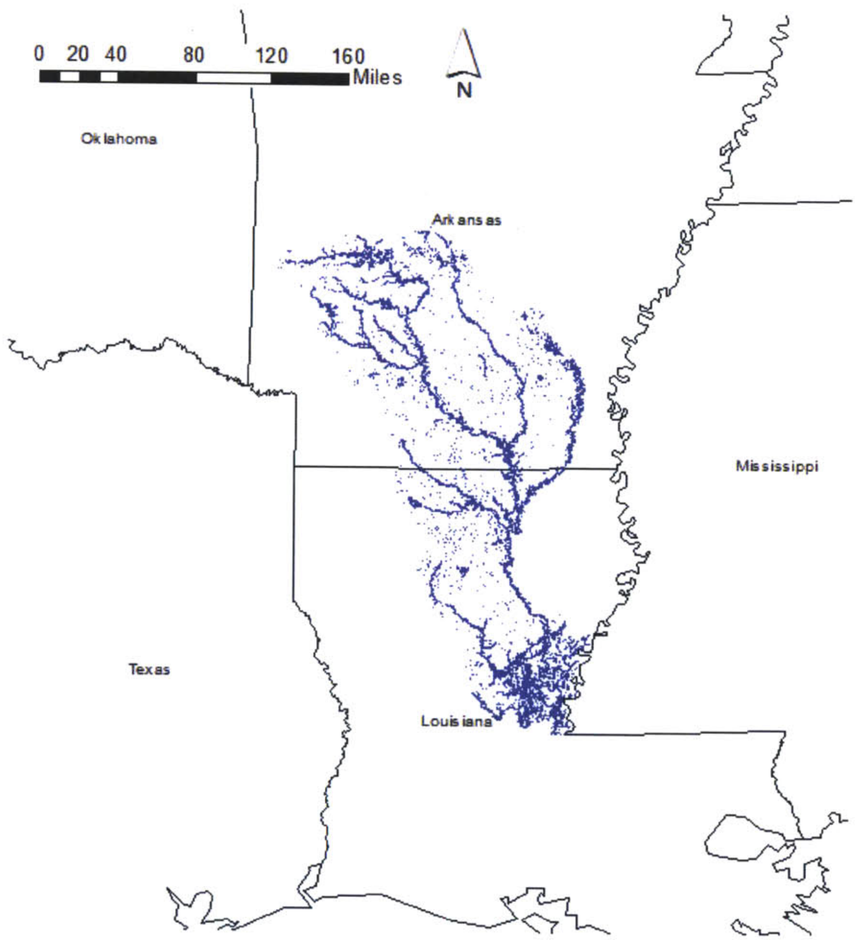

Figure C1: Ouachita River network. (Data from USGS National Hydrography Dataset)

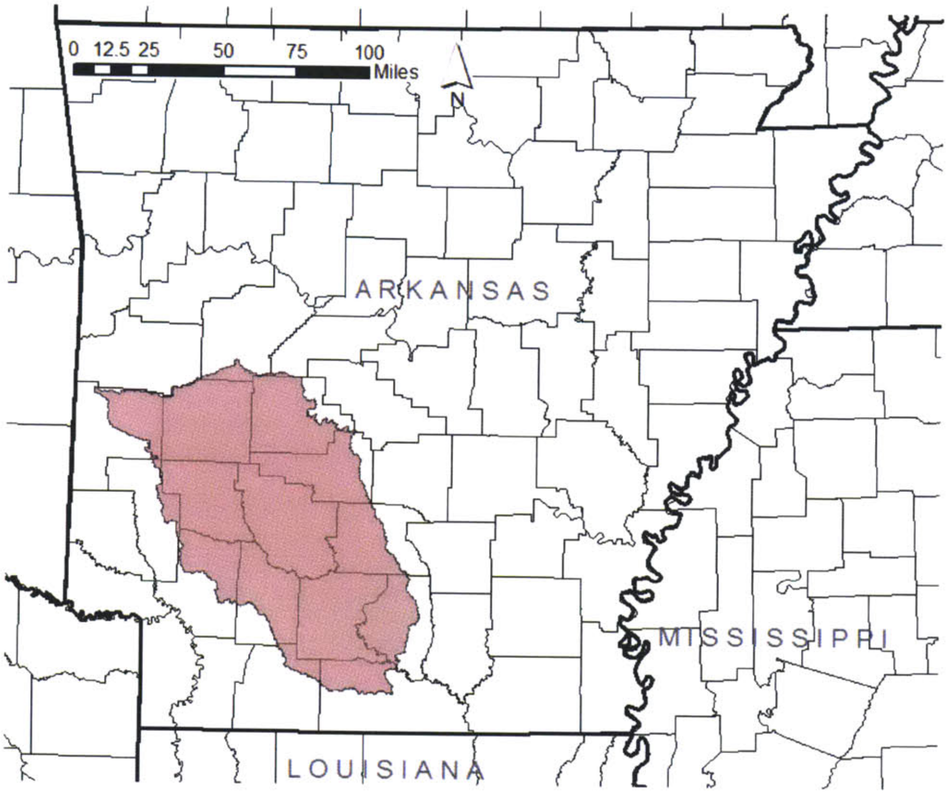

Figure C2: Ouachita River watershed upstream of Union County, Arkansas. (Composite boundary from USGS National Hydrography Dataset and independent delineation)

Table C1: Watershed Characteristics

Characteristic	Value
Basin area[1]	6,528 mi^2
Mean annual precipitation[2]	53.6 in.
Mean annual evaporation[3]	44.9 in.
Mean annual river discharge[4]	16.2 in. (7,785 ft^3/s)

1. From delineated boundary (Figure C2)
2. From areal map of annual precipitation in watershed boundary (Figure C3) and other independent estimates
3. Scott et al. 1998
4. From stream gage USGS 07362000, Ouachita River at Camden, AR, 1928–2011

Water Balance

In a mass balance, the difference of inflows and outflows produces a change in storage. A typical water balance for a watershed can be defined as:

$$P - (ET + R) = \Delta S \quad \text{or} \quad P - ET - R = \Delta S$$

where, in any consistent set of units, P is precipitation, ET is evapotranspiration, R is stream runoff, and ΔS is the change in storage (assumed to be primarily subsurface storage). We have reviewed the data and developed estimates of each of these components for the Ouachita River watershed upstream of Union County. These are presented in Table C2.

a) Precipitation

Figure C3 shows a map of mean annual precipitation in the state from 1961 to 1990. Superposing the watershed boundary as shown, we applied a weighted average to estimate 53.6 in. of average annual precipitation. Monthly distributions of precipitation were obtained from various sources, including the National Oceanic and Atmospheric Administration (NOAA), state agencies, and private entities. While annual estimates are relatively consistent, monthly distributions vary spatially. We ultimately chose a composite dataset from southwest Arkansas as the most representative of mean monthly precipitation in the watershed, with an annual total of 53.6 in. See Table C2.

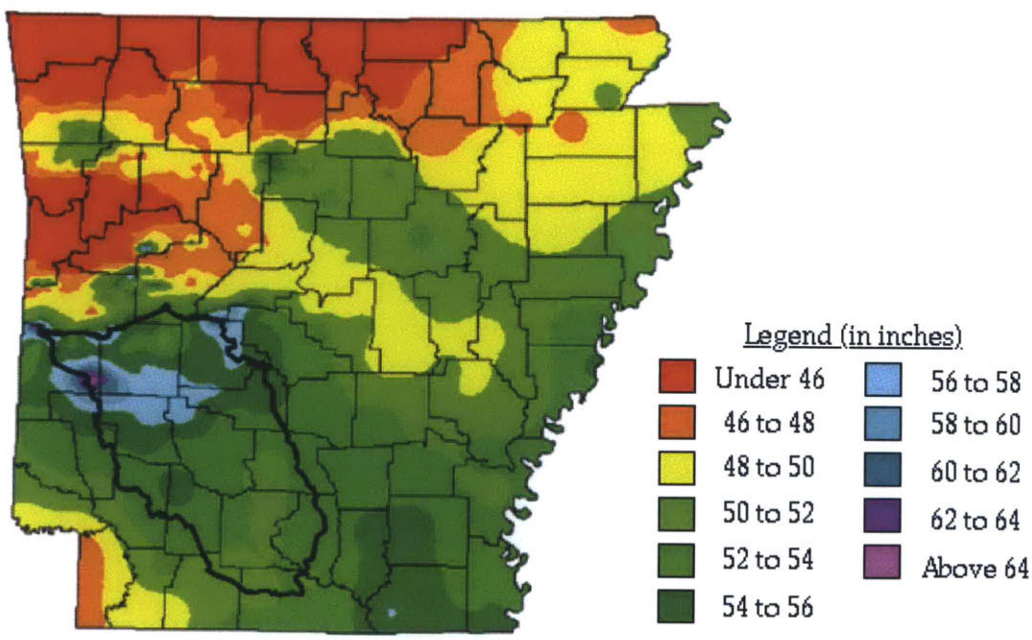

Figure C3: Mean annual precipitation map for Arkansas, 1961–1990. (After WRCC 1997)

b) Evapotranspiration

While precipitation data are copious, evapotranspiration datasets are less abundant. Measuring evapotranspiration is challenging due to the many variables involved. One source (Scott et al. 1998) summarized mean monthly potential evapotranspiration based on pan observations from locations in southern Arkansas from 1960 to 1989. See Table C2.

c) Runoff (Streamflow)

To quantify the runoff component, we reviewed streamflow records from a USGS stream gage at Camden, Arkansas (USGS 07362000). This gage is near the basin outlet point we used to delineate the watershed. The dataset contains monthly mean discharges in ft^3/s from 1928 to 2012. The flows were converted to appropriate units and divided by the watershed area for comparison. See Table C2.

d) Storage

With independent observations of precipitation, evapotranspiration, and runoff, we were able to compute the final term in the water balance, ΔS. We considered this a residual term and attributed all residual to storage (groundwater and soil-moisture fluxes). A positive ΔS represents an increase in storage (infiltration or recharge) and a negative ΔS represents a decrease in storage (exfiltration to the surface). See Table C2.

The data in Table C2 are plotted in Figure C4.

Table C2: Monthly Estimates of Water-Balance Components

Month	Precipitation[1] (in.)	Evapotranspiration[2] (in.)	Runoff[3] (in.)	Change in Storage[4] (in.)
January	6.90	0.89	2.07	3.94
February	5.29	1.45	1.96	1.88
March	5.16	3.09	2.28	–0.21
April	5.10	4.58	2.17	–1.65
May	5.02	5.54	2.21	–2.73
June	3.71	6.38	0.94	–3.61
July	3.41	6.49	0.53	–3.61
August	3.32	5.79	0.40	–2.87
September	3.40	4.42	0.45	–1.47
October	2.91	3.33	0.53	–0.95
November	4.45	1.92	0.97	1.64
December	4.93	1.04	1.68	2.21
Total	53.60	44.92	16.18	–7.43

1. Composite estimates from observations throughout southwest Arkansas
2. Scott et al. 1998
3. From stream gage USGS 07362000, Ouachita River at Camden, AR, 1928–2011
4. Storage is dependent and assumed to be the residual (difference) of the other three components. In this table, positive values represent an increase in groundwater storage and negative values represent a decrease groundwater storage, which is assumed discharge to the surface.

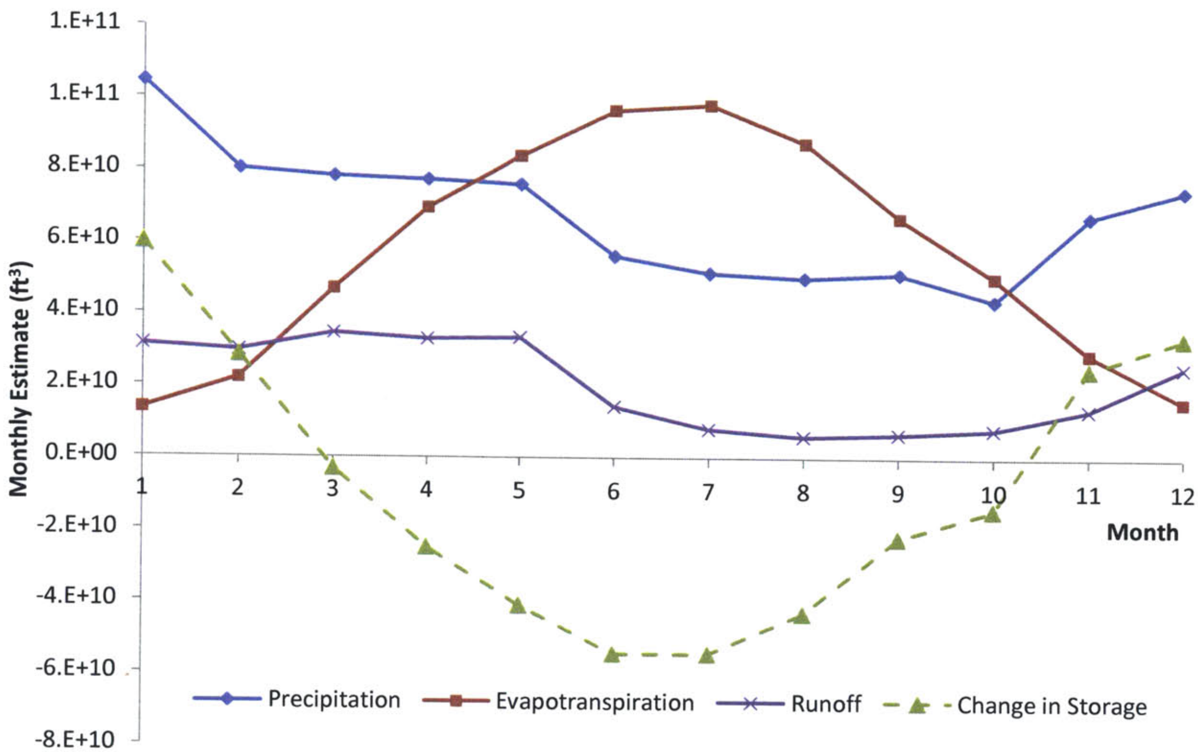

Figure C4: Annual water balance for the Ouachita River upstream of Union County, Arkansas.

Discussion and Conclusions

We observe in Figure C4 the annual and seasonal trends in the water balance. Evapotranspiration has a definite seasonal cycle, with higher rates occurring in the summer. Precipitation follows a somewhat opposite trend, with more precipitation occurring in the winter, but the difference is not as stark as with evapotranspiration. Runoff exhibits a distribution similar to precipitation, though it appears to differ by a constant.

From October to February, the surfacewater system appears to be recharging the storage system; the opposite is true from March to September (Figure C4). Storage provides baseflow during the rest of the year. Notice that evapotranspiration exceeds precipitation in the summer, but runoff continues. This suggests that summer flows are produced by groundwater discharge (a decrease in storage) rather than by precipitation. Notice that on average, there is a net loss of storage in the system; groundwater is exfiltrating as leaving as surface runoff or evapotranspiration.

Appendix D: MODFLOW Data

Table D1: Selected Pre-Modeling Profile Data

K	I	J	Pre-development head (ft)	1997 simulated head (ft)	Top of Sparta Sand (top of Layer 1) (ft)	Bottom of Sparta Sand (bottom of Layer 2) (ft)	Approximate Surface Elevation (ft)
2	193	27	291.14	246.52	124.19	47.86	265.00
2	193	28	288.54	243.59	97.91	−8.56	250.00
2	193	29	285.26	239.72	71.62	−65.03	246.00
2	193	30	276.53	227.72	45.34	−121.18	241.00
2	193	31	269.53	217.53	19.06	−176.61	258.00
2	193	32	264.14	209.06	−7.22	−230.79	270.00
2	193	33	256.60	195.65	−33.50	−284.75	284.00
2	193	34	247.06	177.53	−53.96	−329.85	249.00
2	193	35	238.94	161.06	−61.70	−351.15	272.00
2	193	36	231.86	145.67	−68.67	−370.18	255.00
2	193	37	225.66	131.13	−52.56	−360.88	293.00
2	193	38	220.23	117.30	−19.07	−334.21	292.00
2	193	39	215.47	104.13	−18.47	−340.42	282.00
2	193	40	211.32	91.54	−14.76	−343.54	274.00
2	193	41	207.72	79.46	0.00	−335.78	267.00
2	193	42	204.65	67.96	−100.00	−442.78	246.00
2	193	43	201.65	56.64	−100.00	−449.09	220.00
2	193	44	198.90	46.00	−100.00	−455.05	193.00
2	193	45	196.35	36.36	−20.46	−381.46	165.00
2	193	46	194.10	26.80	−80.07	−447.03	157.00
2	193	47	192.04	17.16	29.21	−343.71	150.00
2	193	48	190.13	7.39	32.66	−346.22	138.00
2	193	49	188.36	−2.57	9.99	−374.85	126.00
2	193	50	186.71	−12.78	−14.01	−404.80	133.00
2	193	51	185.16	−23.31	−23.81	−420.57	186.00
2	193	52	183.69	−34.25	−32.28	−435.30	190.00
2	193	53	182.30	−45.70	−48.83	−458.49	153.00
2	193	54	180.97	−57.76	−50.00	−466.30	179.00
2	193	55	179.69	−70.59	−50.00	−472.94	201.00
2	193	56	178.46	−84.35	−50.00	−485.04	203.00
2	193	57	177.27	−99.24	−50.00	−499.98	195.00
2	193	58	176.14	−115.76	−36.64	−501.58	199.00
2	193	59	175.05	−134.57	−26.25	−506.14	206.00
2	193	60	173.99	−155.30	−22.21	−516.95	230.00
2	193	61	172.96	−188.92	−23.11	−529.20	238.00
2	193	62	171.95	−181.10	−24.15	−539.84	224.00
2	193	63	170.95	−189.76	−28.62	−553.89	220.00
2	193	64	169.96	−212.13	−32.47	−567.32	227.00
2	193	65	168.99	−190.63	−38.53	−582.96	245.00
2	193	66	168.04	−166.20	−44.79	−598.81	240.00
2	193	67	167.13	−147.63	−48.89	−612.50	230.00
2	193	68	166.27	−133.88	−61.90	−635.20	205.00
2	193	69	165.44	−122.88	−84.40	−669.87	193.00
2	193	70	164.57	−113.56	−100.00	−697.66	179.00

K	I	J	Pre-development head (ft)	1997 simulated head (ft)	Top of Sparta Sand (top of Layer 1) (ft)	Bottom of Sparta Sand (bottom of Layer 2) (ft)	Approximate Surface Elevation (ft)
2	193	71	163.65	−105.48	−109.20	−709.20	181.00
2	193	72	162.73	−98.63	−97.38	−697.38	196.00
2	193	73	161.80	−92.76	−86.20	−686.20	217.00
2	193	74	160.84	−87.66	−92.72	−692.72	231.00
2	193	75	159.56	−82.34	−109.37	−709.37	231.00
2	193	76	158.15	−77.15	−124.01	−724.01	229.00
2	193	77	156.77	−72.71	−120.74	−720.74	225.00
2	193	78	155.41	−68.91	−103.38	−703.38	220.00
2	193	79	154.05	−65.67	−60.53	−660.53	224.00
2	193	80	152.70	−62.94	−50.00	−650.00	222.00
2	193	81	151.35	−60.68	−50.00	−650.00	216.00
2	193	82	149.99	−58.86	−50.00	−650.00	211.00
2	193	83	148.63	−57.44	−61.39	−661.39	205.00
2	193	84	147.26	−56.42	−82.28	−682.28	199.00
2	193	85	145.88	−55.79	−70.56	−670.56	195.00
2	193	86	144.49	−55.63	−50.64	−650.64	190.00
2	193	87	143.09	−56.24	−50.00	−650.00	183.00
2	193	88	141.68	−54.99	−50.00	−650.00	169.00
2	193	89	140.24	−54.40	−57.94	−657.94	158.00
2	193	90	138.79	−54.07	−69.64	−669.64	146.00
2	193	91	137.32	−53.87	−81.43	−681.43	133.00
2	193	92	135.82	−53.71	−93.23	−693.23	121.00
2	193	93	134.30	−53.56	−100.00	−700.00	135.00
2	193	94	132.75	−53.40	−100.00	−700.00	147.00
2	193	95	131.17	−53.23	−100.00	−705.93	166.00
2	193	96	129.58	−53.09	−100.00	−717.24	183.00
2	193	97	128.20	−53.00	−100.00	−728.54	183.00
2	193	98	127.04	−53.00	−100.00	−738.38	171.00
2	193	99	125.85	−53.11	−91.82	−738.71	159.00
2	193	100	124.63	−53.32	−77.81	−732.40	150.00
2	193	101	123.40	−53.60	−66.10	−728.41	151.00
2	193	102	122.14	−53.78	−54.94	−724.95	152.00
2	193	103	120.85	−53.55	−50.00	−727.72	153.00
2	193	104	119.54	−53.26	−50.00	−735.43	146.00
2	193	105	118.20	−53.06	−69.54	−762.68	147.00
2	193	106	116.83	−52.98	−93.82	−793.92	140.00
2	193	107	115.43	−53.02	−114.96	−817.15	130.00
2	193	108	114.00	−53.16	−131.37	−835.66	123.00
2	193	109	112.53	−53.37	−141.23	−847.62	116.00
2	193	110	111.04	−53.65	−140.97	−848.68	107.00
2	193	111	109.23	−53.96	−140.00	−848.19	99.00
2	193	112	107.11	−53.89	−139.04	−847.70	90.00
2	193	113	105.00	−53.54	−138.07	−847.21	84.00
2	193	114	103.03	−52.93	−137.10	−845.19	78.00
2	193	115	101.19	−52.36	−138.20	−844.87	72.00
2	193	116	99.46	−51.89	−139.89	−845.13	70.00

K	I	J	Pre-development head (ft)	1997 simulated head (ft)	Top of Sparta Sand (top of Layer 1) (ft)	Bottom of Sparta Sand (bottom of Layer 2) (ft)	Approximate Surface Elevation (ft)
2	193	117	97.82	–51.44	–141.53	–845.35	72.00
2	193	118	96.28	–50.93	–144.03	–846.43	75.00
2	193	119	94.83	–50.34	–146.72	–847.41	78.00
2	193	120	93.50	–49.68	–149.42	–847.38	80.00
2	193	121	92.32	–48.33	–150.00	–844.79	83.00

Table D2: Selected Profile Data for Injection of 3.0 MGD (400,000 ft^3/d) at Location 1
(Hydraulic Head in ft)

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	27	244.20	244.14	244.66	245.13
2	193	28	241.28	241.23	241.76	242.28
2	193	29	237.42	237.37	237.94	238.51
2	193	30	225.34	225.30	225.97	226.69
2	193	31	215.09	215.05	215.83	216.70
2	193	32	206.54	206.51	207.40	208.43
2	193	33	193.01	192.99	194.10	195.45
2	193	34	174.70	174.71	176.16	177.97
2	193	35	158.05	158.08	159.88	162.13
2	193	36	142.46	142.53	144.69	147.40
2	193	37	127.72	127.83	130.38	133.55
2	193	38	113.69	113.85	116.82	120.45
2	193	39	100.30	100.53	103.93	108.04
2	193	40	87.48	87.79	91.66	96.24
2	193	41	75.17	75.59	79.93	84.99
2	193	42	63.43	63.98	68.82	74.33
2	193	43	51.90	52.59	57.95	63.92
2	193	44	41.04	41.91	47.78	54.17
2	193	45	31.21	32.28	38.63	45.38
2	193	46	21.46	22.76	29.61	36.71
2	193	47	11.63	13.22	20.58	28.01
2	193	48	1.67	3.62	11.48	19.25
2	193	49	−8.48	−6.10	2.29	10.36
2	193	50	−18.88	−15.98	−7.07	1.31
2	193	51	−29.60	−26.07	−16.64	−7.98
2	193	52	−40.74	−36.45	−26.50	−17.57
2	193	53	−52.37	−47.17	−36.71	−27.54
2	193	54	−64.62	−58.33	−47.37	−37.96
2	193	55	−77.63	−70.03	−58.60	−48.97
2	193	56	−91.57	−82.40	−70.51	−60.69
2	193	57	−106.64	−95.57	−83.28	−73.28
2	193	58	−123.33	−109.98	−97.33	−87.17
2	193	59	−142.30	−126.13	−113.18	−102.88
2	193	60	−163.18	−143.44	−130.23	−119.82
2	193	61	−196.95	−172.41	−159.02	−148.51
2	193	62	−189.27	−157.68	−144.16	−133.58
2	193	63	−198.06	−154.28	−140.68	−130.05
2	193	64	−220.56	−149.62	−136.01	−125.35
2	193	65	−199.18	−156.30	−142.75	−132.07
2	193	66	−174.86	−144.66	−131.23	−120.55
2	193	67	−156.39	−133.37	−120.10	−109.45
2	193	68	−142.74	−124.36	−111.30	−100.68
2	193	69	−131.82	−116.81	−103.99	−93.42
2	193	70	−122.59	−110.17	−97.63	−87.12
2	193	71	−114.58	−104.22	−92.01	−81.59
2	193	72	−107.80	−99.07	−87.22	−76.90
2	193	73	−101.99	−94.57	−83.12	−72.92
2	193	74	−96.95	−90.61	−79.59	−69.52

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	75	–91.69	–86.38	–75.89	–66.00
2	193	76	–86.56	–82.21	–72.34	–62.66
2	193	77	–82.17	–78.62	–69.35	–59.89
2	193	78	–78.41	–75.52	–66.84	–57.62
2	193	79	–75.21	–72.87	–64.78	–55.79
2	193	80	–72.52	–70.62	–63.10	–54.36
2	193	81	–70.28	–68.76	–61.80	–53.31
2	193	82	–68.48	–67.26	–60.84	–52.60
2	193	83	–67.07	–66.11	–60.21	–52.23
2	193	84	–66.05	–65.30	–59.89	–52.18
2	193	85	–65.42	–64.84	–59.90	–52.47
2	193	86	–65.24	–64.80	–60.31	–53.15
2	193	87	–65.83	–65.50	–61.44	–54.55
2	193	88	–64.55	–64.31	–60.65	–54.04
2	193	89	–63.92	–63.75	–60.47	–54.14
2	193	90	–63.54	–63.44	–60.51	–54.46
2	193	91	–63.28	–63.22	–60.62	–54.86
2	193	92	–63.05	–63.04	–60.75	–55.26
2	193	93	–62.82	–62.84	–60.84	–55.63
2	193	94	–62.57	–62.61	–60.88	–55.96
2	193	95	–62.30	–62.37	–60.89	–56.24
2	193	96	–62.05	–62.13	–60.88	–56.51
2	193	97	–61.86	–61.95	–60.89	–56.74
2	193	98	–61.76	–61.86	–60.94	–56.98
2	193	99	–61.76	–61.87	–61.07	–57.29
2	193	100	–61.86	–61.97	–61.28	–57.69
2	193	101	–62.01	–62.12	–61.53	–58.12
2	193	102	–62.05	–62.17	–61.67	–58.43
2	193	103	–61.67	–61.79	–61.37	–58.31
2	193	104	–61.22	–61.34	–60.99	–58.10
2	193	105	–60.85	–60.97	–60.68	–57.97
2	193	106	–60.59	–60.71	–60.48	–57.93
2	193	107	–60.44	–60.56	–60.38	–57.99
2	193	108	–60.37	–60.49	–60.36	–58.14
2	193	109	–60.38	–60.49	–60.40	–58.34
2	193	110	–60.43	–60.54	–60.49	–58.59
2	193	111	–60.47	–60.58	–60.56	–58.84
2	193	112	–60.06	–60.17	–60.18	–58.68
2	193	113	–59.38	–59.49	–59.54	–58.24
2	193	114	–58.46	–58.56	–58.64	–57.53
2	193	115	–57.59	–57.69	–57.79	–56.87
2	193	116	–56.82	–56.92	–57.05	–56.29
2	193	117	–56.10	–56.20	–56.34	–55.74
2	193	118	–55.32	–55.41	–55.58	–55.12
2	193	119	–54.46	–54.56	–54.73	–54.41
2	193	120	–53.56	–53.65	–53.84	–53.63

Table D3: Selected Profile Data for Injection of 3.0 MGD (400,000 ft^3/d) at Location 2
(Hydraulic Head in ft)

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	27	244.20	246.21	249.75	251.29
2	193	28	241.28	243.36	246.98	248.54
2	193	29	237.42	239.62	243.37	244.96
2	193	30	225.34	227.90	232.08	233.82
2	193	31	215.09	218.03	222.64	224.53
2	193	32	206.54	209.91	214.95	216.99
2	193	33	193.01	197.30	203.18	205.49
2	193	34	174.70	180.47	187.54	190.25
2	193	35	158.05	165.45	173.64	176.73
2	193	36	142.46	151.74	161.00	164.47
2	193	37	127.72	139.20	149.50	153.33
2	193	38	113.69	127.78	139.06	143.26
2	193	39	100.30	117.52	129.72	134.28
2	193	40	87.48	108.49	121.53	126.44
2	193	41	75.17	100.84	114.63	119.88
2	193	42	63.43	94.95	109.37	114.94
2	193	43	51.90	91.40	106.34	112.21
2	193	44	41.04	91.55	106.86	113.00
2	193	45	31.21	98.85	114.37	120.72
2	193	46	21.46	128.07	143.69	150.24
2	193	47	11.63	76.85	92.47	99.19
2	193	48	1.67	48.06	63.56	70.44
2	193	49	−8.48	26.89	42.18	49.20
2	193	50	−18.88	8.97	23.96	31.11
2	193	51	−29.60	−7.31	7.28	14.53
2	193	52	−40.74	−22.75	−8.61	−1.28
2	193	53	−52.37	−37.80	−24.19	−16.78
2	193	54	−64.62	−52.80	−39.77	−32.31
2	193	55	−77.63	−68.07	−55.65	−48.16
2	193	56	−91.57	−83.84	−72.07	−64.56
2	193	57	−106.64	−100.40	−89.28	−81.77
2	193	58	−123.33	−118.30	−107.84	−100.34
2	193	59	−142.30	−138.25	−128.45	−120.97
2	193	60	−163.18	−159.94	−150.77	−143.33
2	193	61	−196.95	−194.35	−185.81	−178.43
2	193	62	−189.27	−187.21	−179.27	−171.96
2	193	63	−198.06	−196.43	−189.08	−181.84
2	193	64	−220.56	−219.28	−212.49	−205.34
2	193	65	−199.18	−198.18	−191.92	−184.87
2	193	66	−174.86	−174.10	−168.34	−161.40
2	193	67	−156.39	−155.81	−150.51	−143.67
2	193	68	−142.74	−142.30	−137.40	−130.68
2	193	69	−131.82	−131.50	−126.98	−120.38
2	193	70	−122.59	−122.35	−118.18	−111.70
2	193	71	−114.58	−114.42	−110.57	−104.23
2	193	72	−107.80	−107.69	−104.15	−97.95
2	193	73	−101.99	−101.93	−98.66	−92.61
2	193	74	−96.95	−96.92	−93.91	−88.01

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	75	–91.69	–91.70	–88.97	–83.27
2	193	76	–86.56	–86.60	–84.17	–78.69
2	193	77	–82.17	–82.23	–80.07	–74.81
2	193	78	–78.41	–78.49	–76.58	–71.54
2	193	79	–75.21	–75.31	–73.62	–68.80
2	193	80	–72.52	–72.62	–71.14	–66.53
2	193	81	–70.28	–70.40	–69.10	–64.71
2	193	82	–68.48	–68.60	–67.47	–63.30
2	193	83	–67.07	–67.20	–66.23	–62.26
2	193	84	–66.05	–66.18	–65.35	–61.60
2	193	85	–65.42	–65.55	–64.85	–61.30
2	193	86	–65.24	–65.38	–64.79	–61.44
2	193	87	–65.83	–65.96	–65.48	–62.34
2	193	88	–64.55	–64.69	–64.30	–61.35
2	193	89	–63.92	–64.05	–63.76	–61.00
2	193	90	–63.54	–63.68	–63.45	–60.88
2	193	91	–63.28	–63.41	–63.26	–60.88
2	193	92	–63.05	–63.19	–63.10	–60.89
2	193	93	–62.82	–62.96	–62.92	–60.90
2	193	94	–62.57	–62.71	–62.72	–60.87
2	193	95	–62.30	–62.44	–62.50	–60.82
2	193	96	–62.05	–62.18	–62.29	–60.76
2	193	97	–61.86	–61.99	–62.13	–60.74
2	193	98	–61.76	–61.89	–62.05	–60.77
2	193	99	–61.76	–61.89	–62.07	–60.89
2	193	100	–61.86	–61.99	–62.18	–61.11
2	193	101	–62.01	–62.14	–62.35	–61.37
2	193	102	–62.05	–62.18	–62.40	–61.52
2	193	103	–61.67	–61.80	–62.03	–61.24
2	193	104	–61.22	–61.35	–61.59	–60.88
2	193	105	–60.85	–60.97	–61.22	–60.60
2	193	106	–60.59	–60.71	–60.97	–60.42
2	193	107	–60.44	–60.56	–60.82	–60.35
2	193	108	–60.37	–60.49	–60.76	–60.36
2	193	109	–60.38	–60.50	–60.76	–60.44
2	193	110	–60.43	–60.55	–60.81	–60.57
2	193	111	–60.47	–60.58	–60.85	–60.68
2	193	112	–60.06	–60.17	–60.44	–60.36
2	193	113	–59.38	–59.49	–59.76	–59.77
2	193	114	–58.46	–58.56	–58.83	–58.92
2	193	115	–57.59	–57.69	–57.96	–58.12
2	193	116	–56.82	–56.92	–57.19	–57.43
2	193	117	–56.10	–56.20	–56.46	–56.77
2	193	118	–55.32	–55.41	–55.68	–56.04
2	193	119	–54.46	–54.56	–54.82	–55.23
2	193	120	–53.56	–53.65	–53.91	–54.37

Table D4: Selected Profile Data for Injection of 3.0 MGD (400,000 ft^3/d) at Location 3
(Hydraulic Head in ft)

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	27	244.20	309.87	313.33	316.89
2	193	28	241.28	316.37	319.83	323.34
2	193	29	237.42	339.11	342.58	346.01
2	193	30	225.34	290.07	293.69	297.07
2	193	31	215.09	264.84	268.60	271.93
2	193	32	206.54	249.01	252.91	256.18
2	193	33	193.01	228.80	232.93	236.12
2	193	34	174.70	203.23	207.65	210.71
2	193	35	158.05	181.10	185.75	188.67
2	193	36	142.46	161.20	166.01	168.81
2	193	37	127.72	142.98	147.88	150.56
2	193	38	113.69	126.09	131.02	133.58
2	193	39	100.30	110.35	115.26	117.70
2	193	40	87.48	95.59	100.42	102.75
2	193	41	75.17	81.68	86.40	88.63
2	193	42	63.43	68.65	73.22	75.35
2	193	43	51.90	56.06	60.43	62.46
2	193	44	41.04	44.36	48.53	50.45
2	193	45	31.21	33.90	37.85	39.69
2	193	46	21.46	23.63	27.34	29.10
2	193	47	11.63	13.37	16.84	18.52
2	193	48	1.67	3.05	6.28	7.88
2	193	49	−8.48	−7.39	−4.40	−2.87
2	193	50	−18.88	−18.03	−15.28	−13.83
2	193	51	−29.60	−28.95	−26.43	−25.05
2	193	52	−40.74	−40.24	−37.95	−36.64
2	193	53	−52.37	−52.00	−49.93	−48.69
2	193	54	−64.62	−64.35	−62.49	−61.31
2	193	55	−77.63	−77.46	−75.79	−74.68
2	193	56	−91.57	−91.46	−89.98	−88.94
2	193	57	−106.64	−106.58	−105.27	−104.29
2	193	58	−123.33	−123.32	−122.16	−121.24
2	193	59	−142.30	−142.32	−141.31	−140.45
2	193	60	−163.18	−163.23	−162.35	−161.55
2	193	61	−196.95	−197.02	−196.26	−195.52
2	193	62	−189.27	−189.36	−188.71	−188.03
2	193	63	−198.06	−198.17	−197.62	−196.99
2	193	64	−220.56	−220.68	−220.22	−219.64
2	193	65	−199.18	−199.30	−198.93	−198.40
2	193	66	−174.86	−174.99	−174.70	−174.22
2	193	67	−156.39	−156.53	−156.30	−155.87
2	193	68	−142.74	−142.88	−142.71	−142.33
2	193	69	−131.82	−131.97	−131.84	−131.51
2	193	70	−122.59	−122.73	−122.66	−122.36
2	193	71	−114.58	−114.72	−114.69	−114.44
2	193	72	−107.80	−107.95	−107.95	−107.74
2	193	73	−101.99	−102.14	−102.18	−102.01
2	193	74	−96.95	−97.09	−97.16	−97.04

K	I	J	$t_{inj} = 0$ yr	$t_{inj} = 1$ yr	$t_{inj} = 4$ yr	$t_{inj} = 20$ yr
2	193	75	–91.69	–91.84	–91.93	–91.86
2	193	76	–86.56	–86.71	–86.83	–86.82
2	193	77	–82.17	–82.32	–82.48	–82.51
2	193	78	–78.41	–78.56	–78.74	–78.83
2	193	79	–75.21	–75.36	–75.57	–75.70
2	193	80	–72.52	–72.67	–72.89	–73.07
2	193	81	–70.28	–70.43	–70.67	–70.90
2	193	82	–68.48	–68.62	–68.88	–69.15
2	193	83	–67.07	–67.22	–67.49	–67.80
2	193	84	–66.05	–66.20	–66.48	–66.83
2	193	85	–65.42	–65.57	–65.86	–66.25
2	193	86	–65.24	–65.39	–65.68	–66.12
2	193	87	–65.83	–65.97	–66.28	–66.75
2	193	88	–64.55	–64.69	–65.01	–65.51
2	193	89	–63.92	–64.06	–64.38	–64.92
2	193	90	–63.54	–63.68	–64.00	–64.58
2	193	91	–63.28	–63.42	–63.74	–64.35
2	193	92	–63.05	–63.19	–63.52	–64.15
2	193	93	–62.82	–62.96	–63.29	–63.95
2	193	94	–62.57	–62.71	–63.04	–63.73
2	193	95	–62.30	–62.44	–62.77	–63.49
2	193	96	–62.05	–62.18	–62.52	–63.25
2	193	97	–61.86	–61.99	–62.32	–63.08
2	193	98	–61.76	–61.89	–62.23	–63.00
2	193	99	–61.76	–61.89	–62.22	–63.01
2	193	100	–61.86	–61.99	–62.32	–63.12
2	193	101	–62.01	–62.14	–62.47	–63.28
2	193	102	–62.05	–62.18	–62.51	–63.33
2	193	103	–61.67	–61.80	–62.13	–62.96
2	193	104	–61.22	–61.35	–61.67	–62.51
2	193	105	–60.85	–60.97	–61.30	–62.14
2	193	106	–60.59	–60.71	–61.04	–61.89
2	193	107	–60.44	–60.56	–60.88	–61.74
2	193	108	–60.37	–60.49	–60.81	–61.67
2	193	109	–60.38	–60.50	–60.81	–61.68
2	193	110	–60.43	–60.55	–60.86	–61.73
2	193	111	–60.47	–60.58	–60.88	–61.76
2	193	112	–60.06	–60.17	–60.47	–61.34
2	193	113	–59.38	–59.49	–59.78	–60.66
2	193	114	–58.46	–58.56	–58.85	–59.73
2	193	115	–57.59	–57.69	–57.98	–58.85
2	193	116	–56.82	–56.92	–57.20	–58.08
2	193	117	–56.10	–56.20	–56.48	–57.36
2	193	118	–55.32	–55.41	–55.69	–56.57
2	193	119	–54.46	–54.56	–54.83	–55.70
2	193	120	–53.56	–53.65	–53.92	–54.79

Table D5: Selected Model Results for Injection at Location 1

Injection duration, t_{inj} (yr)	Year	Stress period	Predefined 1997 with-drawal rate, (ft^3/d)	Injection rate, Q_{inj} (ft^3/d)	Model source/ sink value (ft^3/d)	Simulated 2017 hydraulic head (model result) (ft)	Simulated hydraulic head at critical area (model result) (ft)	Simulated hydraulic-head change, Δh (ft)
0	2017	32	−232,824	0	−232,824	−220.56	−220.56	0.00
0	2017	32	−232,824	100,000	−132,824	−220.56	−220.56	0.00
0	2017	32	−232,824	200,000	−32,824	−220.56	−220.56	0.00
0	2017	32	−232,824	400,000	167,176	−220.56	−220.56	0.00
0	2017	32	−232,824	600,000	367,176	−220.56	−220.56	0.00
0	2017	32	−232,824	800,000	567,176	−220.56	−220.56	0.00
1	2018	33	−232,824	0	−232,824	−220.56	−220.71	−0.15
1	2018	33	−232,824	100,000	−132,824	−220.56	−202.94	17.62
1	2018	33	−232,824	200,000	−32,824	−220.56	−185.16	35.40
1	2018	33	−232,824	400,000	167,176	−220.56	−149.62	70.94
1	2018	33	−232,824	600,000	367,176	−220.56	−114.07	106.49
1	2018	33	−232,824	800,000	567,176	−220.56	−78.52	142.04
2	2019	34	−232,824	0	−232,824	−220.56	−220.85	−0.29
2	2019	34	−232,824	100,000	−132,824	−220.56	−201.34	19.22
2	2019	34	−232,824	200,000	−32,824	−220.56	−181.84	38.72
2	2019	34	−232,824	400,000	167,176	−220.56	−142.83	77.73
2	2019	34	−232,824	600,000	367,176	−220.56	−103.82	116.74
2	2019	34	−232,824	800,000	567,176	−220.56	−64.81	155.75
4	2021	35	−232,824	0	−232,824	−220.56	−221.10	−0.54
4	2021	35	−232,824	100,000	−132,824	−220.56	−199.83	20.73
4	2021	35	−232,824	200,000	−32,824	−220.56	−178.55	42.01
4	2021	35	−232,824	400,000	167,176	−220.56	−136.01	84.55
4	2021	35	−232,824	600,000	367,176	−220.56	−93.47	127.09
4	2021	35	−232,824	800,000	567,176	−220.56	−50.93	169.63
6	2023	36	−232,824	0	−232,824	−220.56	−221.32	−0.76
6	2023	36	−232,824	100,000	−132,824	−220.56	−199.04	21.52
6	2023	36	−232,824	200,000	−32,824	−220.56	−176.76	43.80
6	2023	36	−232,824	400,000	167,176	−220.56	−132.20	88.36
6	2023	36	−232,824	600,000	367,176	−220.56	−87.64	132.92
6	2023	36	−232,824	800,000	567,176	−220.56	−43.07	177.49
8	2025	37	−232,824	0	−232,824	−220.56	−221.53	−0.97
8	2025	37	−232,824	100,000	−132,824	−220.56	−198.59	21.97
8	2025	37	−232,824	200,000	−32,824	−220.56	−175.66	44.90
8	2025	37	−232,824	400,000	167,176	−220.56	−129.80	90.76
8	2025	37	−232,824	600,000	367,176	−220.56	−83.94	136.62
8	2025	37	−232,824	800,000	567,176	−220.56	−38.08	182.48

10	2027	38	–232,824	0	–232,824	–220.56	–221.71	–1.15
10	2027	38	–232,824	100,000	–132,824	–220.56	–198.34	22.22
10	2027	38	–232,824	200,000	–32,824	–220.56	–174.96	45.60
10	2027	38	–232,824	400,000	167,176	–220.56	–128.21	92.35
10	2027	38	–232,824	600,000	367,176	–220.56	–81.46	139.10
10	2027	38	–232,824	800,000	567,176	–220.56	–34.71	185.85
15	2032	39	–232,824	0	–232,824	–220.56	–222.11	–1.55
15	2032	39	–232,824	100,000	–132,824	–220.56	–198.13	22.43
15	2032	39	–232,824	200,000	–32,824	–220.56	–174.14	46.42
15	2032	39	–232,824	400,000	167,176	–220.56	–126.16	94.40
15	2032	39	–232,824	600,000	367,176	–220.56	–78.16	142.40
15	2032	39	–232,824	800,000	567,176	–220.56	–30.14	190.42
20	2037	40	–232,824	0	–232,824	–220.56	–222.45	–1.89
20	2037	40	–232,824	100,000	–132,824	–220.56	–198.18	22.38
20	2037	40	–232,824	200,000	–32,824	–220.56	–173.90	46.66
20	2037	40	–232,824	400,000	167,176	–220.56	–125.35	95.21
20	2037	40	–232,824	600,000	367,176	–220.56	–76.74	143.82
20	2037	40	–232,824	800,000	567,176	–220.56	–28.13	192.43
25	2042	41	–232,824	0	–232,824	–220.56	–222.75	–2.19
25	2042	41	–232,824	100,000	–132,824	–220.56	–198.33	22.23
25	2042	41	–232,824	200,000	–32,824	–220.56	–173.90	46.66
25	2042	41	–232,824	400,000	167,176	–220.56	–125.05	95.51
25	2042	41	–232,824	600,000	367,176	–220.56	–76.15	144.41
25	2042	41	–232,824	800,000	567,176	–220.56	–27.25	193.31
30	2047	42	–232,824	0	–232,824	–220.56	–223.02	–2.46
30	2047	42	–232,824	100,000	–132,824	–220.56	–198.51	22.05
30	2047	42	–232,824	200,000	–32,824	–220.56	–174.01	46.55
30	2047	42	–232,824	400,000	167,176	–220.56	–124.99	95.57
30	2047	42	–232,824	600,000	367,176	–220.56	–75.90	144.66
30	2047	42	–232,824	800,000	567,176	–220.56	–26.89	193.67
35	2052	43	–232,824	0	–232,824	–220.56	–223.26	–2.70
35	2052	43	–232,824	100,000	–132,824	–220.56	–198.71	21.85
35	2052	43	–232,824	200,000	–32,824	–220.56	–174.16	46.40
35	2052	43	–232,824	400,000	167,176	–220.56	–125.05	95.51
35	2052	43	–232,824	600,000	367,176	–220.56	–75.91	144.65
35	2052	43	–232,824	800,000	567,176	–220.56	–26.77	193.79
40	2057	44	–232,824	0	–232,824	–220.56	–223.50	–2.94
40	2057	44	–232,824	100,000	–132,824	–220.56	–198.90	21.66
40	2057	44	–232,824	200,000	–32,824	–220.56	–174.32	46.24
40	2057	44	–232,824	400,000	167,176	–220.56	–125.15	95.41
40	2057	44	–232,824	600,000	367,176	–220.56	–75.96	144.60
40	2057	44	–232,824	800,000	567,176	–220.56	–26.76	193.80

Table D6: Selected Model Results for Injection at Location 2

Injection duration, t_{inj} (yr)	Year	Stress period	Predefined 1997 with-drawal rate, (ft^3/d)	Injection rate, Q_{inj} (ft^3/d)	Model source/ sink value (ft^3/d)	Simulated 2017 hydraulic head (model result) (ft)	Simulated hydraulic head at critical area (model result) (ft)	Simulated hydraulic-head change, Δh (ft)
0	2017	32	0	0	0	–220.56	–220.56	0.00
0	2017	32	0	100,000	100,000	–220.56	–220.56	0.00
0	2017	32	0	200,000	200,000	–220.56	–220.56	0.00
0	2017	32	0	400,000	400,000	–220.56	–220.56	0.00
0	2017	32	0	600,000	600,000	–220.56	–220.56	0.00
0	2017	32	0	800,000	800,000	–220.56	–220.56	0.00
1	2018	33	0	0	0	–220.56	–220.71	–0.15
1	2018	33	0	100,000	100,000	–220.56	–220.35	0.21
1	2018	33	0	200,000	200,000	–220.56	–220.00	0.56
1	2018	33	0	400,000	400,000	–220.56	–219.28	1.28
1	2018	33	0	600,000	600,000	–220.56	–218.57	1.99
1	2018	33	0	800,000	800,000	–220.56	–217.85	2.71
2	2019	34	0	0	0	–220.56	–220.85	–0.29
2	2019	34	0	100,000	100,000	–220.56	–219.79	0.77
2	2019	34	0	200,000	200,000	–220.56	–218.73	1.83
2	2019	34	0	400,000	400,000	–220.56	–216.61	3.95
2	2019	34	0	600,000	600,000	–220.56	–214.50	6.06
2	2019	34	0	800,000	800,000	–220.56	–212.38	8.18
4	2021	35	0	0	0	–220.56	–221.10	–0.54
4	2021	35	0	100,000	100,000	–220.56	–218.94	1.62
4	2021	35	0	200,000	200,000	–220.56	–216.80	3.76
4	2021	35	0	400,000	400,000	–220.56	–212.49	8.07
4	2021	35	0	600,000	600,000	–220.56	–208.19	12.37
4	2021	35	0	800,000	800,000	–220.56	–203.88	16.68
6	2023	36	0	0	0	–220.56	–221.32	–0.76
6	2023	36	0	100,000	100,000	–220.56	–218.48	2.08
6	2023	36	0	200,000	200,000	–220.56	–215.63	4.93
6	2023	36	0	400,000	400,000	–220.56	–209.93	10.63
6	2023	36	0	600,000	600,000	–220.56	–204.23	16.33
6	2023	36	0	800,000	800,000	–220.56	–198.51	22.05
8	2025	37	0	0	0	–220.56	–221.53	–0.97
8	2025	37	0	100,000	100,000	–220.56	–218.22	2.34
8	2025	37	0	200,000	200,000	–220.56	–214.92	5.64
8	2025	37	0	400,000	400,000	–220.56	–208.31	12.25
8	2025	37	0	600,000	600,000	–220.56	–201.66	18.90
8	2025	37	0	800,000	800,000	–220.56	–195.00	25.56

10	2027	38	0	0	0	−220.56	−221.71	−1.15
10	2027	38	0	100,000	100,000	−220.56	−218.10	2.46
10	2027	38	0	200,000	200,000	−220.56	−214.48	6.08
10	2027	38	0	400,000	400,000	−220.56	−207.23	13.33
10	2027	38	0	600,000	600,000	−220.56	−199.93	20.63
10	2027	38	0	800,000	800,000	−220.56	−192.63	27.93
15	2032	39	0	0	0	−220.56	−222.11	−1.55
15	2032	39	0	100,000	100,000	−220.56	−218.07	2.49
15	2032	39	0	200,000	200,000	−220.56	−214.02	6.54
15	2032	39	0	400,000	400,000	−220.56	−205.85	14.71
15	2032	39	0	600,000	600,000	−220.56	−197.67	22.89
15	2032	39	0	800,000	800,000	−220.56	−189.48	31.08
20	2037	40	0	0	0	−220.56	−222.45	−1.89
20	2037	40	0	100,000	100,000	−220.56	−218.20	2.36
20	2037	40	0	200,000	200,000	−220.56	−213.94	6.62
20	2037	40	0	400,000	400,000	−220.56	−205.34	15.22
20	2037	40	0	600,000	600,000	−220.56	−196.72	23.84
20	2037	40	0	800,000	800,000	−220.56	−188.09	32.47
25	2042	41	0	0	0	−220.56	−222.75	−2.19
25	2042	41	0	100,000	100,000	−220.56	−218.38	2.18
25	2042	41	0	200,000	200,000	−220.56	−214.01	6.55
25	2042	41	0	400,000	400,000	−220.56	−205.19	15.37
25	2042	41	0	600,000	600,000	−220.56	−196.34	24.22
25	2042	41	0	800,000	800,000	−220.56	−187.47	33.09
30	2047	42	0	0	0	−220.56	−223.02	−2.46
30	2047	42	0	100,000	100,000	−220.56	−218.58	1.98
30	2047	42	0	200,000	200,000	−220.56	−214.15	6.41
30	2047	42	0	400,000	400,000	−220.56	−205.20	15.36
30	2047	42	0	600,000	600,000	−220.56	−196.21	24.35
30	2047	42	0	800,000	800,000	−220.56	−187.22	33.34
35	2052	43	0	0	0	−220.56	−223.26	−2.70
35	2052	43	0	100,000	100,000	−220.56	−218.78	1.78
35	2052	43	0	200,000	200,000	−220.56	−214.30	6.26
35	2052	43	0	400,000	400,000	−220.56	−205.28	15.28
35	2052	43	0	600,000	600,000	−220.56	−196.21	24.35
35	2052	43	0	800,000	800,000	−220.56	−187.13	33.43
40	2057	44	0	0	0	−220.56	−223.50	−2.94
40	2057	44	0	100,000	100,000	−220.56	−218.96	1.60
40	2057	44	0	200,000	200,000	−220.56	−214.45	6.11
40	2057	44	0	400,000	400,000	−220.56	−205.39	15.17
40	2057	44	0	600,000	600,000	−220.56	−196.27	24.29
40	2057	44	0	800,000	800,000	−220.56	−187.11	33.45

Table D7: Selected Model Results for Injection at Location 3

Injection duration, t_{inj} (yr)	Year	Stress period	Predefined 1997 with-drawal rate, (ft^3/d)	Injection rate, Q_{inj} (ft^3/d)	Model source/ sink value (ft^3/d)	Simulated 2017 hydraulic head (model result) (ft)	Simulated hydraulic head at critical area (model result) (ft)	Simulated hydraulic-head change, Δh (ft)
0	2017	32	0	0	0	−220.56	−220.56	0.00
0	2017	32	0	100,000	100,000	−220.56	−220.56	0.00
0	2017	32	0	200,000	200,000	−220.56	−220.56	0.00
0	2017	32	0	400,000	400,000	−220.56	−220.56	0.00
0	2017	32	0	600,000	600,000	−220.56	−220.56	0.00
0	2017	32	0	800,000	800,000	−220.56	−220.56	0.00
1	2018	33	0	0	0	−220.56	−220.71	−0.15
1	2018	33	0	100,000	100,000	−220.56	−220.70	−0.14
1	2018	33	0	200,000	200,000	−220.56	−220.69	−0.13
1	2018	33	0	400,000	400,000	−220.56	−220.67	−0.11
1	2018	33	0	600,000	600,000	−220.56	−220.66	−0.10
1	2018	33	0	800,000	800,000	−220.56	−220.64	−0.08
2	2019	34	0	0	0	−220.56	−220.85	−0.29
2	2019	34	0	100,000	100,000	−220.56	−220.79	−0.23
2	2019	34	0	200,000	200,000	−220.56	−220.72	−0.16
2	2019	34	0	400,000	400,000	−220.56	−220.59	−0.03
2	2019	34	0	600,000	600,000	−220.56	−220.47	0.09
2	2019	34	0	800,000	800,000	−220.56	−220.34	0.22
4	2021	35	0	0	0	−220.56	−221.10	−0.54
4	2021	35	0	100,000	100,000	−220.56	−220.88	−0.32
4	2021	35	0	200,000	200,000	−220.56	−220.66	−0.10
4	2021	35	0	400,000	400,000	−220.56	−220.22	0.34
4	2021	35	0	600,000	600,000	−220.56	−219.77	0.79
4	2021	35	0	800,000	800,000	−220.56	−219.31	1.25
6	2023	36	0	0	0	−220.56	−221.32	−0.76
6	2023	36	0	100,000	100,000	−220.56	−220.98	−0.42
6	2023	36	0	200,000	200,000	−220.56	−220.64	−0.08
6	2023	36	0	400,000	400,000	−220.56	−219.94	0.62
6	2023	36	0	600,000	600,000	−220.56	−219.21	1.35
6	2023	36	0	800,000	800,000	−220.56	−218.47	2.09
8	2025	37	0	0	0	−220.56	−221.53	−0.97
8	2025	37	0	100,000	100,000	−220.56	−221.10	−0.54
8	2025	37	0	200,000	200,000	−220.56	−220.66	−0.10
8	2025	37	0	400,000	400,000	−220.56	−219.75	0.81
8	2025	37	0	600,000	600,000	−220.56	−218.83	1.73
8	2025	37	0	800,000	800,000	−220.56	−217.89	2.67

10	2027	38	0	0	0	−220.56	−221.71	−1.15
10	2027	38	0	100,000	100,000	−220.56	−221.21	−0.65
10	2027	38	0	200,000	200,000	−220.56	−220.71	−0.15
10	2027	38	0	400,000	400,000	−220.56	−219.65	0.91
10	2027	38	0	600,000	600,000	−220.56	−218.58	1.98
10	2027	38	0	800,000	800,000	−220.56	−217.48	3.08
15	2032	39	0	0	0	−220.56	−222.11	−1.55
15	2032	39	0	100,000	100,000	−220.56	−221.50	−0.94
15	2032	39	0	200,000	200,000	−220.56	−220.88	−0.32
15	2032	39	0	400,000	400,000	−220.56	−219.58	0.98
15	2032	39	0	600,000	600,000	−220.56	−218.27	2.29
15	2032	39	0	800,000	800,000	−220.56	−216.86	3.70
20	2037	40	0	0	0	−220.56	−222.45	−1.89
20	2037	40	0	100,000	100,000	−220.56	−221.78	−1.22
20	2037	40	0	200,000	200,000	−220.56	−221.08	−0.52
20	2037	40	0	400,000	400,000	−220.56	−219.64	0.92
20	2037	40	0	600,000	600,000	−220.56	−218.17	2.39
20	2037	40	0	800,000	800,000	−220.56	−216.60	3.96
25	2042	41	0	0	0	−220.56	−222.75	−2.19
25	2042	41	0	100,000	100,000	−220.56	−222.03	−1.47
25	2042	41	0	200,000	200,000	−220.56	−221.29	−0.73
25	2042	41	0	400,000	400,000	−220.56	−219.75	0.81
25	2042	41	0	600,000	600,000	−220.56	−218.17	2.39
25	2042	41	0	800,000	800,000	−220.56	−216.51	4.05
30	2047	42	0	0	0	−220.56	−223.02	−2.46
30	2047	42	0	100,000	100,000	−220.56	−222.26	−1.70
30	2047	42	0	200,000	200,000	−220.56	−221.49	−0.93
30	2047	42	0	400,000	400,000	−220.56	−219.88	0.68
30	2047	42	0	600,000	600,000	−220.56	−218.23	2.33
30	2047	42	0	800,000	800,000	−220.56	−216.49	4.07
35	2052	43	0	0	0	−220.56	−223.26	−2.70
35	2052	43	0	100,000	100,000	−220.56	−222.47	−1.91
35	2052	43	0	200,000	200,000	−220.56	−221.67	−1.11
35	2052	43	0	400,000	400,000	−220.56	−220.02	0.54
35	2052	43	0	600,000	600,000	−220.56	−218.30	2.26
35	2052	43	0	800,000	800,000	−220.56	−216.50	4.06
40	2057	44	0	0	0	−220.56	−223.50	−2.94
40	2057	44	0	100,000	100,000	−220.56	−222.66	−2.10
40	2057	44	0	200,000	200,000	−220.56	−221.84	−1.28
40	2057	44	0	400,000	400,000	−220.56	−220.15	0.41
40	2057	44	0	600,000	600,000	−220.56	−218.39	2.17
40	2057	44	0	800,000	800,000	−220.56	−216.54	4.02